Readable Books in Natural Knowledge

THE CHANGEFUL EARTH

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THE CHANGEFUL EARTH

AN INTRODUCTION TO THE RECORD OF THE ROCKS

BY

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PUBLISHERS' NOTE

So much attention is now given to the practical and systematic study of science in schools, that the valuable influence of descriptive scientific literature is apt to be overlooked. An intimate knowledge of the simplest fact in Nature can be obtained only by personal observation or experiment in the open air or the laboratory, but broad views of scientific thought and progress are secured best from books in which the methods and results of investigation are stated in language which is simple without being childish.

Books intended to promote interest in science must differ completely from laboratory guides, text-books, or works of reference. They should aim at exalting the scientific spirit which leads men to devote their lives to the advancement of natural knowledge, and at showing how the human race eventually reaps the benefit of such research. Inspiration rather than information should be the keynote; and the execution should awaken in the

reader not only appreciation of the scientific method of study and spirit of self-sacrifice, but also a desire to emulate the lives of men whose labours have brought the knowledge of Nature to its present position.

These are the objects of the series of Readable Books in Natural Knowledge to which the present volume belongs. Each volume will endeavour to stimulate interest in the studies with which it is concerned, and to present natural phenomena and laws broadly and attractively. It is hoped that the books will provide the reading matter urgently required in connection with the science work in schools and will appeal also to a wide circle of other readers. The series should be of service in directing attention to the nobility of scientific ideals and the ultimate value of results obtained by careful and faithful work.

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Our souls, whose faculties can comprehend
The wondrous architecture of the world,
And measure every wandering planet's course,
Still climbing after knowledge infinite,
And always moving as the restless spheres,
Will us to wear ourselves, and never rest,
Until we reach the ripest fruit of all.

MARLOWE, *Tamburlaine*.

CHAPTER I

MAN AND THE EARTH'S SURFACE

THIS little book deals with a great subject. We have no right to live on the earth without trying to learn something about it. The earth itself, then, is to be our subject; but we can, after all, deal only with what lies very near its surface. Even in a well-ventilated mine, where fresh air is drawn in at one shaft and the used air is drawn out at another, we can barely descend a mile into the earth's interior. Nearly four thousand miles lie between us and the centre of the globe. All sorts of wonderful things may be going on down below us, where the rocks are, in places at any rate, very highly heated, and where they are pressed and squeezed by all that lies above them. Vast masses of pure iron, huge lumps of yellow gold or tin-
...te platinum, diamonds as big as oranges, and
worthy of an enchanted palace in a fairy-
ay be hidden safely in the mysterious depths,
m the covetous grasp of man. But we need

not dream about these depths, when so much lies in the surface-layers, ready to our hands.

When man first learned how to hold his own against the wild beasts round about him, he was no doubt living in caves, where caves were handy, or up in the trees, in countries where forests were his only shelter. He walked out of his cave, or he climbed down cautiously from his tree, and looked about him. He was seeking weapons with which to meet his foes. If he killed an animal, he generally ate it, and ate it very simply. Many of the old cave-dwellers used wild horses commonly as food. The skins and hides of animals also had their value, and tools were needed with which to remove them neatly and prepare them. In looking for tools and weapons, man was really beginning his study of the earth.

He used sticks to defend himself; but stones were his proper weapons. They could be thrown from a distance, and sharp ones would penetrate the flesh. Presently he learned how to trim stones until they had cutting edges; and at last he invented the proper form of the adze, the arrow-head, and the spear. Some kinds of stone were far better than others for his purpose; he tested them, and judged them by their hardness, and chose what we now call flint wherever this came within his reach (Fig. 1).

How long was it before early man began to see the beauty of hill and vale, stream and woodland, round about him? Not very long, perhaps, though he could not write down his thoughts, or

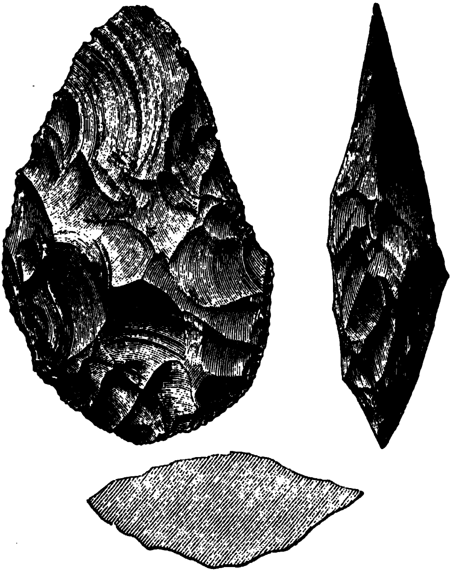

FIG. 1.—Flint Implements of the Older Stone Age.

even express them very clearly in spoken words. He looked for running water, and he found that the valley was comfortable where the spring flowed out among moss-covered stones, and on through meadows where the grass was never parched or withered. Trees became pleasant and familiar to

him, just as bare hillsides seemed horrid and distasteful. Now that he could mark out a homestead and defend it, he formed his camp on the margin of the woodland, and left its dark recesses to the savage beasts. All kinds of mysterious things went on there behind him; but he had now taken his place as a conqueror on the open surface of the world.

Too often in the cities, which have grown up with successive centuries, we forget this open world all round us. But men have gone out from time to time across it, and have tried to read the story of the earth. They have had to learn from rocks and rivers, or on the shores of sounding seas; they have climbed among mountain-peaks, and have taken counsel with the wise old race of men who work below in mines. When once the passion for such study seized them, they felt that they must travel and learn more. No books written by the cleverest of mortals could help them, until they had seen the wonders of the earth itself. "The stones thereof are the place of sapphires, and it hath dust of gold." One by one, they brought back some new treasure. The specimens thrown aside on a mine-heap, because they were useless in the arts, proved often the most beautiful and delightful to enquiring minds. When these travellers and observers came to talk over their

discoveries, they did not always agree, and they had fine long discussions on winter evenings. A whole new knowledge had to be built up, and even now we have only got a small part of it together. What we know, or hope we know, we call GEOLOGY, the science of the earth.

The more we know of this science, the more grateful we are to those who laid its foundations, in times when travel was far harder than it is to-day. The ordinary man, keeping his eyes open, may add something to our subject whenever he gives himself a holiday. Indeed, the lives of the geological discoverers were not always very eventful in themselves. They set out intent on knowing something, and not on capturing cities or on breaking other people's heads. The more modest they were in relating their discoveries, the more influence they have had on the minds of thinking people. They made man look again at the old earth round about him, and he found that it had a history far, far longer than his own. He found that the rain that falls and the wind that blows continually change its surface; that one part of the world is growing, while another wastes away. He found that a continent may still be rising out of the ocean, while an ocean-bed may change its place and form. This world on which we live has a life and a life-work of its own, and of this we must not

remain ignorant. Come, we can all be geologists in our own way; and we have the pioneers before us, to show us how to set to work.

Sir Archibald Geikie has set forth the lives of the pioneers in his book on *The Founders of Geology*, and perhaps the chapters that here follow may lead to the reading of this and many a larger treatise. For, when we have made a start, we have an open road before us. As James Hutton, one of our greatest geologists, wrote in 1785, "Man is not satisfied, like the brute, in seeing things which are; he seeks to know how things have been, and what they are to be." And, two hundred years before, Kit Marlowe said the same, in still more glowing words.

CHAPTER II

SEA-SHELLS IN THE MOUNTAINS

1. Sea-Shells on the Shore

Come and sit down on the beach in the warm sunshine, and watch the tide flowing gently in upon the land. Round us are all manner of beautiful sea-shells, dark-blue mussels with purple shades in them, pink scallops with one valve flatter than the other, brown and well-curved cockles, marked

with strong ribs and with little notches on the inner margin, and here and there a big grey twisted whelk-shell, or a yellow limpet knocked off the rocks, looking like the hat of a doll Chinaman. What becomes of all these shells, now that the delicate animals, mussels and sea-snails and so forth, have died away out of them, and they lie cast up here amid the sand? Some are already broken; the big whelk has a hole in its side, through which we can see the hollow of the shell winding like a spiral staircase round its central column. Other shells are mere fragments, and very few that possess two valves, like the mussels, have these valves still joined together, as they were when the animal was alive. The sand itself is full of pieces of broken shells; parts of the beach are practically made up of them.

The shell-fish for the most part do not live on the beach, which runs dry between the tides. Some of those with one valve, like the limpets and the periwinkles, cling tightly to the rocks on which they sit, and, when the water goes down, wait for a few hours until they get safely covered up again. The mussels, moreover, hang in dark-blue clusters to the woodwork of the pier; but the other common shells, which move about freely in the water, enjoy themselves farther out in the bay. Here in the deeper water no stones are rolled over

them, and even the sand and mud that are washed down from the land are not sufficient to annoy them when they gape open and take their food. Now and then, after big storms, you can see the shell-fish in a living state in the pools amid the sand, and very active some of them are as they move or even skip across the bottom. But as a rule only dead shells are washed on to the shore; there must be a far greater accumulation of these in the banks out at sea where the shell-fish live and feed.

The waves, breaking and falling on the shallows, spread out the dead shells with the sand before our feet. Day after day, tide after tide, the water is arranging this loose material, now angrily stirring it up when the wind blows fiercely on the shore, but on the whole smoothing it out and keeping it flat and even. As the tide goes back, it carries away some of the finer material from between the coarser grains of sand, and the beach becomes thus clean and shining, and almost too stony in certain places, while the mud and fine sand removed from it are deposited quite a long way out from land. Of course, when a river runs over a clay country, it brings down too much fine material for the sea to deal with properly, and then we get mud-banks close to shore, like those that form unpleasant features in the Thames. Whether far out or on

the beach itself, these muds must also contain hundreds and thousands of sea-shells.

Look also at the little white streaks that lie on the surface of the smoother sand. They have been washed up out of the main material by the gentle sifting action of the waves. Even with the unaided

FIG. 2.—Modern Foraminifera, magnified.
(From a photograph by Mr. J. E. Barnard.)

eye, tiny white shells can be seen in them abundantly. With a pocket-lens, these shells appear as little curled or oval forms of the most exquisite delicacy. They are the coverings of the tiny and humble animals known by the big name of "foraminifera." Some little things deserve big names, lest they should be passed over and for-

gotten. The term "foraminifera" refers to the fact that they have small holes or openings in the structure of their shells, through which they thrust parts of their bodies when alive. In deeper water, the remains of these tiny shells accumulate without much sand or mud between them. When dredged up from, say, five hundred fathoms (3000 feet), the deposit formed by them is a greyish-white mud styled "ooze." From still greater depths we may get such oozes almost pure. The foraminifera, whether living at the surface or on the bottom, are here beyond the reach of deposits from the shore; larger shell-bearing animals, moreover, such as our whelks and cockles and sea-urchins, do not freely thrive so far from land.

On the ocean-floor, then, an ooze may accumulate, composed almost entirely of foraminiferal remains. In lesser depths, foraminifera and common shell-fish and sea-urchins may mingle, without much material from the land. Even in the sands and muds of the actual shore, shells may become embedded at every tide.

2. Sea-Shells in the solid Rocks

Now let us come far inland, a hundred miles or more if you will, and seek quite a different kind of scene. You may sit down on the grassy terraces of the Derbyshire uplands, with grey walls

of limestone dropping beneath you into the dales; or you may wander in the wooded valleys at the back of the Cotteswold ridge, and note the yellow quarries opened here and there amid the fields. The very stones in these fields are full of interest. Pick one up, or for that matter knock off a fragment of the grey limestone in northern England. The forms of shells and corals are likely to be seen in either of these specimens. You will say at once that these objects are known as "fossils." The term is now quite a common one; but it is in these simple familiar remains, hard and solid in the solid rock, that we may read chapter after chapter of the varied history of the earth.

You will not doubt, in this twentieth century, what these fossils really are. They are the remains of shell-fish and other animals that lived in old days on the spots where now we pick them up. If they are like the kinds of animals that live in the sea at the present day, the sea must have covered both the Derbyshire uplands and the Cotteswold Hills in times that have long passed away. We may soon learn that remains of fish, like sharks and skates, have been found side by side with the fossil shells. If we look more closely, we shall see that the rocks of these regions were actually formed on old sea-bottoms. The hills themselves have been carved out of beds that were laid down by the

sea like those upon our modern shore. These sandstones with shell-fragments in them were once sands upon a beach; these clays were once the muds that formed in deeper waters; these limestones are almost entirely made of shells, and deserve study with a microscope. Even with a pocket-lens, we can see how the very ground of them consists of broken shells, spines of sea-urchins, bits of coral, or of the stems of those quaint animals known as sea-lilies. The microscope shows us in addition foraminifera, almost as perfect as when they fell on the sea-floor. These represent the deposits of the purer portions of the sea. All these rocks show their origin by being arranged in layers; we say that they are "stratified," or composed of "strata."

FIG. 3.—Foraminifera in Limestone. Magnified 100 diameters.

We take all this quite calmly nowadays; but such observations record for us the most remarkable changes that have occurred on the surface of the earth. Although some of the old Greek philosophers concluded from the discovery of fossil shells that the

land and the sea must have changed places, it was long before the minds even of learned men could feel persuaded on the matter. Very many of them became convinced that some mysterious force existed

FIG. 4.—Marine Beds, clearly stratified, forming part of a mountain-region, Bourg d'Oisans, Isère, France. (G. Cole photo.)

in the earth, whereby stony imitations of living objects were fashioned in the solid rocks. Even the bones of elephants, found buried in old gravels, were held to have been formed there as a sport of nature. Here and there, however, real observers came into the field, and urged that this crust of the

earth, on which we live, was like a thin skin, wrinkling up and down, now letting in the ocean over a dry area, and allowing marine shells to gather there, now lifting the sea-floor again and bringing up " fossils " to our view.

If we feel no doubt about this nowadays, it is because of an immense amount of travel, labour, and observation on the part of those who have gone before us. We now can see easily what they have discovered and shown to us; but we can form only a small idea of the long struggle by which the truth ultimately came to light. Even now we know very little about the forces that heave the thin crust up and down; we only know that it moves, and that sea-shells have been carried 10,000 feet high upon the hills.

3. Movements of the Sea-Floor

Are we sure that the rocks have moved, and that the sea has not merely withdrawn and left them dry? This question was answered in 1669 by Nicolaus Steno, a Dane, who became tutor to the sons of the Grand Duke of Tuscany, and finally wore out his strength as a devoted priest of the Roman Catholic Church. Steno was famous for his work in human anatomy; but in Italy, where the rivers have cut deeply into the soft rocks on

the margins of the Apennines, he had ample opportunities of seeing fossil shells; and he noticed that the beds containing them were not always

FIG. 5.—Folded Marine Limestones, Loughshinny, Co. Dublin, overlain by boulder-clay. (G. Cole photo.)

level or nearly level, as they would have been when deposited in the sea. Movement of the rocks must have occurred, for the beds are uptilted, and even folded together like a cloth. In the British Isles, these folds are often seen, and in larger

mountain-districts they can be clearly traced on thousands of feet of bare rock-walls.

Was all this work of upheaval done at once, and is the earth now at rest? Observations all over the world have shown that movements of the crust took place at various times. Mountain-masses were upheaved, were carved out by the weather into peaks and valleys, and then again sank beneath the sea. New beds with tell-tale marine shells in them were laid down on the worn and irregular surface, covering up its hills and hollows; and yet again the whole mass was crumpled, and new land was once more formed. Again and again these changes have taken place, not by some sudden shattering, but so slowly that no living being in its own lifetime could have traced out what was going on. Instead of being blotted out and destroyed in some huge catastrophe, as many of the older writers fancied, the plants and animals went on living, shifting their homes as these gradually became unsuitable.

But is anything of this kind going on now? The movements are so slow that the question is hard to answer. It is well known, however, as Sir Charles Lyell long ago told us, that streets in the south of Sweden have sunk below the level of the sea, while in other places dead barnacles have been seen still attached to the rocks where no tide now

could reach them, remaining, in fact, 100 to 200 feet above the water. The marks set for the purpose in 1792 in the rocks in southern Sweden were carefully examined a hundred years later. They indicate an uplift in that time of nearly one metre —say 3 feet—as the greatest movement that has occurred. The Stockholm area has risen half a metre, so that at this rate in a thousand years the city will stand 17 feet higher above the sea. A rise of 17 feet would enormously increase the power of the rivers to cut down their valley-floors, and would render long stretches unnavigable where the sea now flows in, and where steamers ply. Islets would be largely extended, and some would be united to the mainland. When we go back to what is called the younger Stone Age, we observe, from the presence of old sea-beaches on the land, that large parts of Sweden were at that time under water. If we had anything like the real history of man upon the earth, we should find that he has survived amid amazing changes in the level of the surface.

In the west of the United States, terraces cut in the solid rock by wave-action, like those so often seen in Norway, have been found more than 1200 feet above the sea. Charles Darwin, again, noticed, as far back as 1835, that beaches with modern marine shells occur on the Pacific coast of South America

at heights from 85 to 1300 feet above the sea. At Lima in Peru he found plaited rushes and cotton string, the work of natives, embedded in the beach; and he argued that the elevation of the coast, in this case 85 feet, must have taken place since man was in the country.

FIG. 6.—Sea-beach raised 37 ft. by the earthquake of September 1899, west side of Disenchantment Bay, an arm of Yakutat Bay, Alaska. (From Prof. Tarr's memoir, *Bull. Geol. Soc. America*, 1906.)

One of the most striking cases of recent uplift was described in 1906 by Prof. R. S. Tarr and Mr. L. Martin. An earthquake occurred in Alaska in September 1899, and at Yakutat Bay, east of Mount St. Elias, the coast was found to have been raised by

amounts varying from 7 to 47 feet. Barnacles and mussels were lifted high and dry, and sea-caves and beaches remain out of reach of the waves to bear witness to what Prof. Tarr regards as the greatest change of level recorded in historic times (Fig. 6).

In Sicily, beds of marine shells, almost all of which are like those living on the present Mediterranean floor, are found nearly 3000 feet above the sea. Even in our own islands, "raised beaches" are common, containing modern types of shells. Parts of southern Scotland have been raised, perhaps since man came on the earth, at least 100 feet, while an old beach runs round nearly all the east and north of Ireland, lifted from about 8 to 20 feet above high-water mark. At Larne, in the county of Antrim, flints chipped by man occur side by side with sea-shells in this beach, showing that the uplift occurred during the human epoch.

Some of the regions where such signs of movement occur are shaken by earthquakes, like California, Alaska, and Sicily; but others are wonderfully free from them. The great uplifts and downsinkings of the crust are not in themselves due to the sudden shocks that we call earthquakes. Great earthquakes are probably due to the slipping of the rocks along cracks that have been formed in them, and are thus accidents, as it were, accompanying the general swayings of the crust.

It is curious to look at a map, or better still at a globe, and to think that the edges of the continents and of the great oceans are really shifting, through the action of strange forces down below them. It has often been pointed out that an insect may live all its life on a tree, that generations of others may follow it, and yet none of them may know that the tree has a life of its own and is growing taller all the time. A boy, however, may plant a chestnut, and see a fine tree rise from it long before he reaches middle age. Similarly we can imagine beings outside our earth living far longer lives than ours, and watching this fine old ball rolling on with the sun through space; and to them the movements of continents and ocean-floors may be actually visible, appearing as great waves rising and falling on its surface.

But we have now travelled a long way from our modern beach and from the bed of fossil shells that we found up in the hills. Let us gather as many fossils as we can from different places, and see what they have to tell us of the long history of life upon the globe.

CHAPTER III

WILLIAM SMITH AND THE ENGLISH MIDLANDS

1. In the Cotteswold Hills

Travellers from London, before they reach the Severn valley in the pleasant west of England, must climb across the Cotteswold Hills. On the main routes to Worcester, to Gloucester, or to Bath, the roads ascend steadily over a broad monotonous slope, until the edge is reached, perhaps 1000 feet above the sea, and the ground falls suddenly and steeply into the western plain. Far away across the windings of the river, we see the broken ranges on the Marches, leading to the stubborn land of Wales.

This upland of the Cotteswolds, which is so steep towards the north-west, so gentle in its descent to the south-east, is made of stratified rocks. We see their layers in the yellow quarries that have been cut out along the western scarp. Yellow stone lies everywhere round us, a rubbly limestone for the most part. We may pick up flaky fragments in the fields, and find plenty of fossil shells in them. As we have said, we all agree nowadays that these beds are of marine origin. The sea must once have spread over the Mid-

lands. Its floor became tilted up, with the shelly beds upon it; the weather, working against the highest part of the mass, then carved out the steep face, while the slope of the strata forms the long descent south-eastward.

The main water-courses thus run in a south-easterly direction, and the Thames itself rises on the Cotteswold slope. Though the back of the hills seems bare and wind-swept, with scattered farms and stony fields, woods often lie in the hollows cut by running water. The villages are set down there by the streams, though several towns, successors of old British camps and Roman strongholds, still stand boldly on the barren upland. Everywhere the old marine limestones are used for building. The rough walls along the roads, here taking the place of hedges, are made of flaggy limestone, broken roughly from the beds. The old farm-houses and village inns, with their Tudor gables and fine tall chimney-stacks, are built of limestone blocks, squared in local quarries by workmen of the sixteenth century. The very roofs are made of stone slabs, coloured grey and yellow during centuries by clinging lichens. In this country the well-stratified limestone, crossed by joint-cracks that make it ready for the mason, has always given architects plenty of material, and the tower of a village church will sometimes seem worthy of a cathedral.

The traveller who does not mind crossing a stiff country is sure of a welcome in these old-world villages. There is no grime of coal-mines or iron-works about them. Each man tills the stony soil; or he quarries the rock and puts the rubble on the roads, which are rarely much the better for his labour; or he works in some way in the grounds or stables of "the Hall," of which you have seen the gates as you go by. Good manners and a kindly spirit prevail throughout the country-side, and the people are strong, clean, and reasonably contented, which is more than can always be said of those who are crowded into factory towns.

We cannot fail to notice how the face of the Cotteswold Hills rises up against us, as we come out of the Severn valley above Gloucester and climb to the village of Birdlip above the yellow limestone quarries. We go over the crest, and down east as far as Oxford, and we find that the rubbly limestones have been here exchanged for clays, which overlie them. Then, above the flatter clay-land, a second scarp rises, with white quarries of chalk in it, set in the face of smooth and grassy hills. Perhaps we shall see on the green slopes one of those white horses cut out by the removal of the turf, which are used to decorate the landscape in accordance with an ancient local custom. This second range forms the Chiltern

Hills; we climb them, descend through the beech-woods on their backs, and come into a level country of stiff clays and occasional flat-topped sandy hills near Windsor.

The same succession of rocks is found across England if we start from Bath. The yellowish shelly limestones form the hilly country to Devizes. Here the chalk ridge, with old British camps upon the crests, meets us far sooner than on the Oxford road; and we come on the clays of the Windsor and London area before we have passed through Newbury. Far away in the north, again, we find Lincoln on its scarp, a city planted high against the sky like some Italian hill-town; and here we recognize the same features as those of the Cotteswold Hills. The scarp is formed of the same limestones, protecting the same slope of clays below. Here also, in the east, the chalk comes out above the yellow limestone series, forming the long ridge of the Lincolnshire Wolds.

Such broad features of the country were noticed by many intelligent travellers so far back as the eighteenth century. They saw that the structure of the English midlands was clearly due to the laying down of bed after bed of rock, one upon another. The tilting of these beds gave rise to the long parallel ranges, much as when several books are laid upon one another on a slope. The higher beds are

clearly younger than those below them. The beds in the eastern midlands are thus younger than the limestones of the Cotteswold edge.

So much was apparent to those who drove about in post-chaises, before railways were invented, and before travellers had become accustomed, on a long journey, to keep their eyes fixed on sixpenny magazines. In those times travel was a leisurely and serious occupation, and men walked or rode quite as often as they took the public coach. A hundred miles was an important undertaking. Some men, intent on spending the money that prudent fathers had gathered up for them, dashed down in "elegant equipages" from London to fashionable Bath, just as the people stream down the same highroad nowadays in motor-cars. But hundreds of quiet citizens went on plodding through the country, plain-spoken merchants who journeyed with their packs from town to town. Into their world William Smith was born, in 1769, at Churchill in the west of Oxfordshire. He has been called the Father of English Geology, for he was the first to show us how to read the story of life upon the globe. He learned this lesson from the rocks piled one upon another in the Cotteswolds. Let us try to see how he set about it.

2. The Education of William Smith

William Smith's father owned a farm at Churchill; but he died when the boy was seven years old. William was brought up by an uncle of the same name, who was a practical farmer also, at Over Norton. Life, for all but the rich, was much harder then than it is at the present day. Wages were low, food was usually dear, and the expense of carting goods across the country made people content with common things. Plain William Smith received a very simple education in the village school. Among a race of farmers, it was natural that he should take an interest in the land, and he was not slow in noticing the fossils to be found on it. The sea-urchins, indeed, that dropped out of the yellow limestones were so large and common as to be known as "poundstones," and were used as pound weights by the women in the dairies.

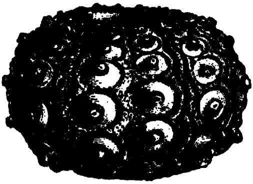

Fig. 7.—Sea-urchin from Upper Jurassic strata. Two-thirds natural size.

Smith studied geometry, and a neighbouring land-surveyor, Edward Webb, took him, at the age of eighteen, as an assistant. Webb lived in the high-perched town of Stow-on-the-Wold, and young

William Smith entered his house as one of his family. Webb was a man of some ingenuity, and certainly encouraged his pupil to observe. Smith knew already from his boyhood that there was plenty to learn in the quarries and roadside-cuttings among his native limestone hills. Steep lanes and open plateaus had alike given him stones enough to think about, and down below Churchill there were great valleys of a more clayey character, which must be crossed on any journey to Worcester and the cities of the west. When Smith travelled in his new career, it was on some definite occupation. Something had to be done, land had to be measured, or the line of a new canal established. The rise and fall of the surface of the landscape must have taken a place naturally in his thoughts; and we can imagine his pleasure in noting how the beds of rock that he had left behind as he descended into the valley reappeared on the next rise, with the same types of corals or sea-shells sticking out on their weather-beaten ledges.

In 1791, when he was two-and-twenty years of age, his master sent him to survey an estate at Stowey in Somersetshire, eight miles south of Bristol, and it was most convenient to walk there, a distance of some eighty-five miles. He went across the head-waters of the Thames to Cirencester, and thence to Bath, down what was then one of the main

coach-roads. He climbed the plateau again south of this fine city, which is built almost entirely out of the yellow limestone of the Cotteswolds; and again from hollow land at Radstock he saw the Mendip Hills rise up, with an older limestone in their centre. He turned north here towards Bristol, noting the coal-beds, a thing new to him, as he went; and we may be sure that he surveyed a good deal while at Stowey besides the estate that called him thither.

Three years later, Smith, now twenty-five years old, was sent on tour in connexion with a great canal scheme, which Parliament had sanctioned. His companions were Dr. Perkins and Mr. Palmer, who had the engineering questions in their minds. They drove together from Bristol to York and Newcastle, covering altogether nine hundred miles. Here was an education for the young geologist, on a route full of pleasure and interest for any one who will follow it in our days. Smith tells how he sat forward in the post-chaise, to see the features of the landscape. "My friends," he says, "were interested in two objects; but I had three, and the most important one to me I pursued unknown to them." He had all the excitement of being a discoverer in his native land. The English Midlands were to him the courts of a university. His masters were the long hill-ranges, stretching one behind another

against the sunrise, a source of delight as each day dawned upon the road.

3. Smith finds Friends at Bath

What was it that forced itself upon the mind of William Smith as he travelled throughout England? Not only the succession of the strata, the Cotteswold limestone above the Lias clay, and so on, but the fact that the fossil remains in the strata also succeeded one another in a regular order. He gathered the shells and other hard parts of animals, which in his time were styled "organized fossils," and compared those from one level with those found higher or lower down. Observing that the kinds of animal remains were not quite the same in successive strata, he went on to prove that this change in the fossils was not an accident peculiar to one part of the Midlands, but was repeated in many other places. And here is the point on which he insisted: *the kinds of fossils always succeeded one another in the same order.* Hence, if we once recognized that order, we could reason backwards, and say that, because we found such and such fossils in a rock, this rock belonged to a particular level in the great series of strata that recorded the past history of the earth. The strata of the Cotteswold area are now styled "Jurassic," since

their fossils show them to be of the same age as the rocks that form the Jura Mountains.

Smith's professional journeys had shown him that his principles were sound, and we find him

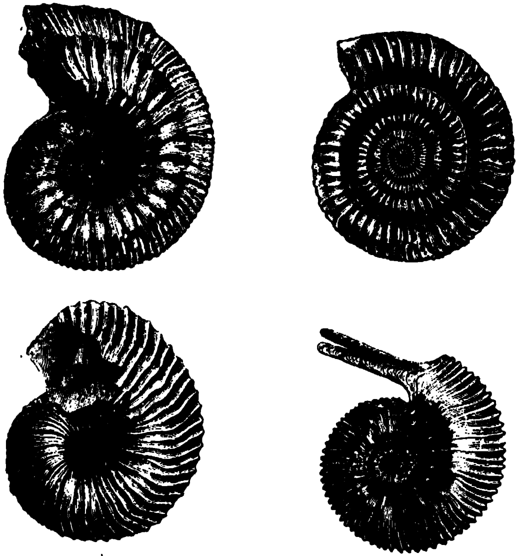

FIG. 8.—Shells of Cephalopods (Ammonites) from Jurassic strata of England, showing different types from successive beds.

settled at Bath in 1795, in a house high above the town, with a fine view north to Monmouthshire. He was here engaged as a civil engineer on the construction of the Somerset Coal Canal, a waterway that starts near the collieries above Radstock, passes quickly into rural country by Dunkerton and

Midford, and descends into the wooded valley of the Avon, where it joins the canal that connects the Bristol Channel with the Thames. A good deal of

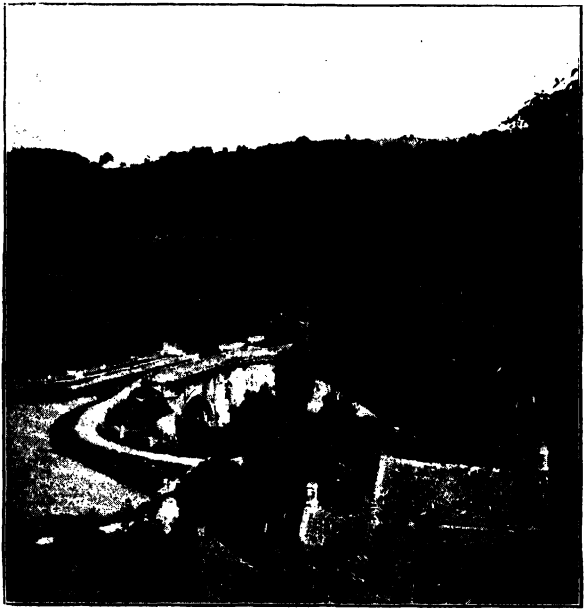

FIG. 9.—Valley of the Avon, in the Cotteswolds, east of Bath, with canal carried across the river. (G. Cole photo.)

building, and even of architecture, was associated with these old canals, as we may see by the handsome bridges that carry them across roads or rivers. We may be sure that young William Smith visited the quarries, as well as his own excavations, and saw

as much as he could of the strata at various levels of the hills (Fig. 9).

The steep cuts made by the rivers near Bath, going down 400 feet below the general plateau, offered him even finer advantages than he had found as a boy near Churchill. He moved into the country at Midford, and even bought a small property on the canal side. His best fortune, however, lay in meeting two good friends in Bath, the Rev. Benjamin Richardson and the Rev. Joseph Townsend, of Pewsey, near Marlborough. Smith showed them, about 1799, how he had determined the order of succession of various beds of rock, and had noted the fossils peculiar to each horizon. His list included strata as old as the Coal-Measures of Bristol, and as recent as the Chalk of Marlborough Downs.

So beautiful and well-ordered a country, from a geological point of view, cannot fail to have its effect on those who live in it; and the educated clergy of the west of England have always been among the most generous workers in the field of science opened up by William Smith. Richardson and Townsend lost no opportunity of spreading Smith's conclusions among their scientific friends, and by 1801 his discoveries were known even on the Continent of Europe. Smith now developed the idea of making geological maps, in which the

colours should indicate the beds in which particular groups of fossils could be found. Before his time, such maps showed different kinds of rocks, but gave no distinct idea of their relative ages, or of their position in the whole series that was known. A manuscript map made by William Smith of the country around Bath may be regarded as the foundation of all our geological maps at the present day.

In 1800 William Smith rode from Bath to Holkham on the coast of Norfolk, and returned by the Fenland to Peterborough and Northamptonshire. He used John Cary's one-sheet map of England on this journey, and in later years laid down geological boundary-lines on a number of Cary's county maps. He never wrote great books; nor could he quote Latin authors, or invent high-sounding terms in Greek for plain and honest things. But he could tell his friends clearly what he saw, and would take them out of their libraries into the country and make them see with their own eyes. His friends helped him loyally in spreading abroad his views, and by the time he was thirty years of age he had set geology on a new foundation.

4. Strata identified by Fossil Remains

How William Smith worked at his science, in spite of his constant professional duties, is shown

by his production of a large map of England and Wales in 1815, coloured geologically, on the principles of that which he first attempted for the single county of Somerset. He rightly called this map the "first general mineralogical survey of the island." In his Memoir descriptive of the map, he goes on to say: "I have, with immense labour and expense, collected specimens of each stratum, and of the peculiar extraneous fossils, organic remains, and vegetable impressions, and compared them with others from very distant parts of the island, with reference to the exact habitation of each, and have arranged them in the same order as they lay in the earth; which arrangement must readily convince every scientific or discerning person that the earth is formed as well as governed, like the other works of its great Creator, according to regular and immutable laws, which are discoverable by human industry and observation, and which form a legitimate and most important object of science." Smith points out that numerous practical advantages will arise from the study of geological maps. In a book published two years later, his *Stratigraphical System of Organized Fossils*, he adds that, to one who observes soils and strata while he travels, "his own house will be the best school of Natural History for all the younger branches of the family, . . . nor with such re-

sources can a country gentleman be (as Pope says) 'a prisoner in his own house every rainy day.' Rural amusements, to those who can enjoy them, are the most healthful; and the search for a Fossil may be considered at least as rational as the pursuit of a hare. . . . Natural History should be the first object of every country gentleman; and if it be not an insult to nature to pass unnoticed her various productions, which are superior far to the nicest workmanship, it will sometime be an insult to the understanding to be considered totally ignorant of these things."

Here we have the sound opinion of hard-working William Smith, who was taught in the village school and in the office of a country land-surveyor. We are yet a very long way from the ideal that he pictured when he wrote in 1817. There are thousands of British citizens and country gentlemen, and hundreds of members of Parliament for that matter, trained in our public schools and universities, who look upon the study of the earth as something that in no way concerns them, and who often would regard it as "an insult to their understanding" if they were supposed to know anything about it. They leave scientific studies, which they called "stinks" at school, to those who are going to invent something for our material comfort, such as a new electric railway or a patent sanitary

soap. William Smith knew far better than this, though he took care to show again and again how his scientific discoveries bore upon practical affairs. In the quaint style of his day, he writes from his own experience that "endless gratification may be derived from mountains of animated nature, wherein extinct animals and plants innumerable, with characters and habits distinctly preserved, have transmitted to eternity their own history, and the clearest and best evidence of the earth's formation."

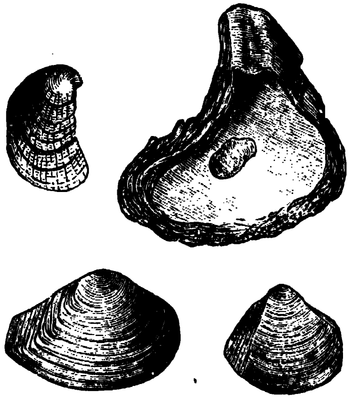

FIG. 10.—Oyster and other Fossil Bivalves from Upper Jurassic Rocks of England.

Between 1816 and 1819, Smith issued a famous work called *Strata identified by Organized Fossils*, which is now unfortunately very rare. Only four parts were published, but they made a great impression, coming as they did after his map of England. The pictures of fossils were printed on papers of various colours, to represent the general colours of the beds in which they lay. Some of the pages were thus quite dark and muddy-looking; but the

shells were pleasantly painted on them by hand, and the colour of the background was meant to aid the memory. The collection on which this book was founded was presented to the British Museum, and can now be consulted by any one interested in it in the Natural History Museum at South Kensington.

Smith's list of strata was naturally not quite

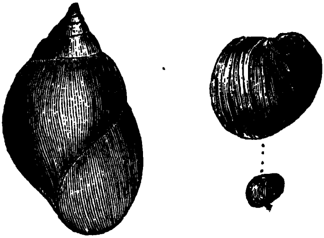

Fig. 11.—Marine Univalves from Middle Jurassic Limestones of England.

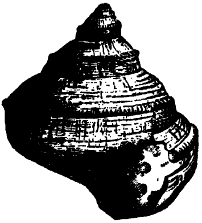

Fig. 12.—Marine Univalve from Upper Jurassic Clay of England.

perfect, and it contained one or two errors as to the order of the beds. It dealt very lightly with the mass of older strata in Wales, the Lake District, and Cornwall, the fossils of which are obscure, and lie in regions difficult to traverse. Smith, however, worked with his relative John Phillips in the Lake District as early as 1821, and produced a geological map of it for the publisher Cary. It was still left for Sedgwick and Murchison to bring the old rocks into order, by the use of Smith's principles, between 1830 and 1855.

5. The Father of English Geology

Smith moved from the Lake District to live near the beautiful limestone hills which rise above Kirkby Lonsdale. From this home he went to give lectures on his favourite study before societies in York and Hull. Little as he wrote, and seldom as he spoke in public, he had fully merited the fine title bestowed on him by Professor Sedgwick. Sedgwick in 1831, as president of the Geological Society of London, presented Smith with the first medal awarded by that society. He asked the members if they did not feel compelled to place their "first honour on the brow of the Father of English Geology."

While Smith was a young man, other geologists, far more learned, were not content with his patient mode of study. By the time that his views came to be published, some of the great scientific disputes had quieted down, and people were ready to listen to one whose ideas were based on careful observation. Though the delight of overcoming difficulties and of penetrating unknown lands had very properly laid a strong hold upon geologists, shrewd and sagacious men began to realize that it was better at that stage to study a small region in all its details, rather than to attack the problems of a continent, and build up loose and general theories

of the earth. William Smith studied the earth's history from the records of the rocks themselves.

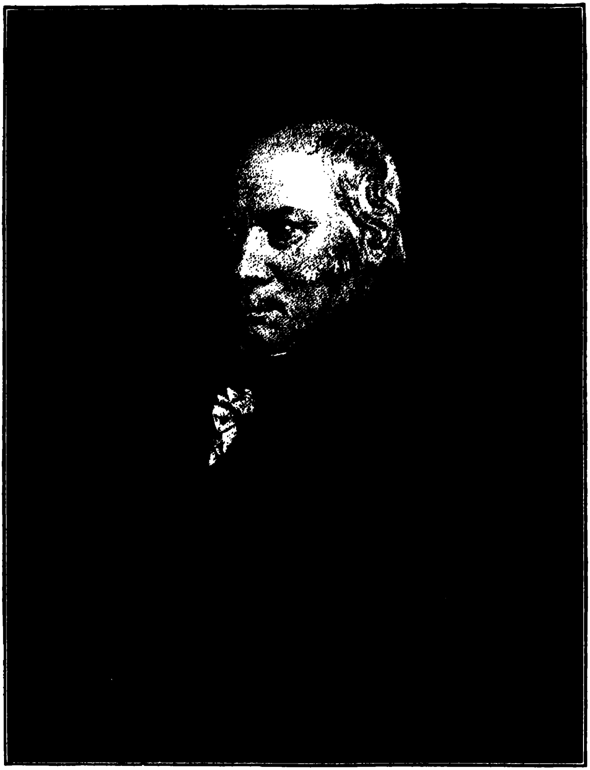

FIG. 13.—William Smith (age 69), from the engraving by T. A. Dean, after the portrait by Foureau.

He had resolved to read those records, instead of guessing at their contents from a brilliant and

attractive portion picked up here and there. He died at a good age in 1839, honoured among all geologists. His portrait hangs over the president's chair in the rooms of the Geological Society of London; and to look on his plain honest features is to remember what one man can perform, when he takes the earth as his teacher and writes truly what he sees.

CHAPTER IV

SHELL-BEDS IN THE PARIS BASIN

1. The Country around Paris

The discoveries of William Smith were being quietly spread abroad among his friends, and no regular publication of them took place until his fine map was ready for the students of the world. Meanwhile, two observers were busy in a very interesting region beyond the English Channel. Every one knows Paris, the city of broad streets and uniform stone-built houses, which has taken the place of the cramped mediæval town, rich in gables and pinnacles, that grew up on and around an island in the Seine. But few people except Parisians know the open country round the city, as you may see it in Jules Breton's pictures; an

expanse of immense fields, with here and there a strip of hedgerow, and the church-spire of some quaint old village rising a mile away above a welcome clump of trees. There are shady forests also, neat and well regulated, with straight paths running through them between squares of closely planted trees; and, finally, if you follow up the Seine, you come to Melun, whence the broken ground of Fontainebleau stretches southward, covered with a superb mass of natural woodland. Here pine and birch, reminding us of the mountains, have been preserved beside beech-trees and gigantic oaks, to furnish cover for the sports of kings. The projecting masses of sandstone seem quite wild and rugged after the level plain; and a large part of the busy world of Paris never goes beyond Fontainebleau in search of the picturesque. On the farther edge of the forest, some seventeen miles from Melun, we find the old-world town of Moret, walled and gated, which stood at one time as a fortress of the frontier, with all that could be called France behind it, and the Burgundian enemy on the east.

The less romantic ground nearer to Paris has, however, its irregularities. The strata of which it is formed are level, but the weather has had some effect upon them. Steps are seen across the landscape, where one horizontal bed has been worn back

farther than another, and the tributaries of the Seine have cut pleasant valleys, on the sides of which we may come across sections of the strata. Yellowish rocks are seen in quarries that have been opened up for building or for road-metal. Fossil shells, very beautifully preserved, may often be found in these excavations, and even in the flints that are used upon the roads. All this forms a pleasant country to wander in. The houses are often set down quite simply, without fences, in the middle of their well-tilled lands. Through the arched stone gateway of some seventeenth-century farm we see the threshing-machine at work. Another house has its stacks of oats reared round it like golden towers. Peasants are moving this way and that across the open fields, all intent upon gaining something from the soil. Even the old women help their families, and each one leads a single cow throughout the day, slowly pasturing it along the roadside. Behind these friendly scenes, some castle tower, like that of tall Montlhéry, reminds us of the days when men kept these fields against raiders from Burgundy or from England.

2. The Students of the Paris Basin

All this land feeds Paris; and Paris attracted scholarly and thinking men long before the foundation of her university in the early part of the

thirteenth century. Age after age, these men discussed all manner of affairs, and quarrelled richly over their differences of opinion, without paying much attention to the wonders of the ground beneath them. Near the close of the eighteenth century, however, many people were rather tired of the speculations of philosophers who sat at home. In fact, they began to see that what happened in nature was not always in agreement with what their schoolmasters supposed. People began to feel that the true philosopher was the man who made experiments, who patiently measured and compared his minerals or his shells, who tested the composition of the air, or wandered over half a continent to find plants hitherto unknown.

This movement of thought, which made men doubt, and question, and discover, was spreading steadily throughout Europe. Its rougher side was revealed in the wild acts of the French insurgents, and much that was wise and helpful was crushed out for a time in the bitter years of revolution. But, under all those scenes of public turmoil, the spirit of the founders of modern science moved quietly on its way. In every town of western Europe, some patient worker was even then showing us more and more of the beauty of the common things that lie all about us on the earth. Sometimes, as we read their published memoirs,

an echo of the great wars in Europe reaches us. De Saussure, for instance, the explorer of the Alps, complains in 1794 that he could not get enough coal to melt his minerals for his experiments. He had to work, therefore, on tiny fragments, melting them with a candle and a blow-pipe, and examining the products with a microscope; and excellent work he did in this direction. All this was on account of the high price of fuel on the Swiss border, ravaged as it was by contending armies, before whose hungry needs everything else must stand aside.

Research went on, and the learned Academies continued to publish their results, while the hail of the French guns crashed into the ice at Austerlitz, and the smoke-pall of Bavarian villages blotted out the summer stars. A hundred successive harvests have grown upon those blood-stained fields; states and kingdoms, founded in violence, have vanished from the map of Europe; but the example of those honest workers remains to encourage us for all time. Even Napoleon Bonaparte, restlessly moving eastward, and trampling on the thrones of Europe as he went, loved to be accompanied by men who could bring new knowledge from the conquered lands. The desire to understand things was abroad; and not even the worst tyranny could crush it down.

It was in these turbulent days that the shallow

basin of stratified rocks in which Paris stands began to receive real attention. The great French naturalist, Lamarck, knew many of its fossil shells; and Leopold Georges Cuvier settled in Paris in 1795, and found abundant matter ready to his hand. Cuvier was born a German citizen and was educated at Stuttgart. Like so many students of nature, he began his work as a teacher; but he soon had a career rich in success and even in worldly honours. We so often hear of poor scholars rising to unexpected fame, that it is just as well to remember that a rich man is not necessarily an idle one. Many of those who have added to knowledge in our own islands have worked from pure love of working, and not from any need of gain. The possession of money has not made them less industrious. Cuvier's friends used to regret that he was drawn away into politics, and that he loved public distinction, as many lesser men are apt to do. But his success was due to a fine power of sticking to what lay before him; and he could do more in a day than some of his critics could have thought of in a week.

When Cuvier received his first professorship at the École Centrale of Paris in 1795, he became known as a comparative anatomist. That is to say, he compared the structure of one type of animal with another, and became especially skilled in the

study of the forms of bones. His acuteness in this respect was revealed more than ever when he began to examine the fossil remains of back-boned animals in the quarries of the Paris basin. These diggings, which supply the city with limestone for building, gypsum for plaster, and clay for bricks, gave him excellent opportunities; but the bones in them are often mixed together, and those of several animals may be crowded into a small space. The quaint old-world creatures no doubt gathered at certain drinking-pools, as our mammals do to-day in the oases, and sometimes they perished there, from old age or from the attacks of their flesh-eating companions. In other places, year after year, their remains were swept down into some quiet hollow of a stream. Already broken asunder, their skeletons became greatly entangled and confused. It required a Cuvier to give us an idea of how these animals were constructed when they lived.

His extraordinary knowledge of the whole range of living back-boned animals enabled him to tell the general nature of an extinct mammal from the discovery of two or three of its bones. In this way he made known the existence of ancient allies of the tapirs in the north of France, and of other mammals that now live in warmer climates. He also showed that these old types were not quite

the same as any forms now living on the earth. Lamarck had taught that living things might change their structure in the course of generation after generation, and that animal species thus became greatly modified in successive geological ages. Cuvier, however, was not prepared to admit that the fossil forms were the ancestors of the

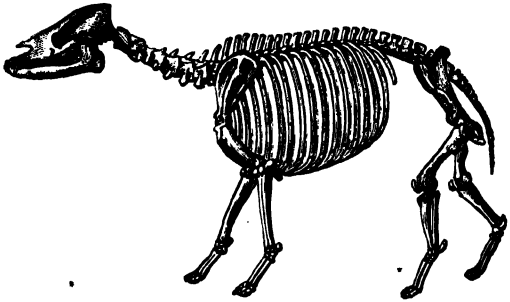

FIG. 14.—Palæotherium, a Mammal allied to the Horse, from the Eocene Beds of Paris. $\frac{1}{37}$ natural size.

modern ones. He believed that from time to time "revolutions," more complete than that raging in the political world round him, had occurred throughout the globe, and had entirely swept away the older groups of animals. The world had then been re-peopled by a newly created set of species. This view was common enough in Cuvier's time, and was the only one that found support in England. William Smith was content to keep clear from speculation; but he regarded his groups of fossils,

laid out so distinctly in the great stratified series, as successive creations appropriately formed for the beds in which they were entombed.

When Cuvier had satisfied himself that animal life had become changed from time to time during a long series of geological epochs, he was well prepared to study in detail the rocks of the Paris basin. Week after week, from 1800 onwards, he wandered over the open country which we have already pictured to ourselves. In this task he found an admirable companion. Alexandre Brongniart had served in the medical branch of the French army, and devoted his leisure to zoology. In those days, it was possible for a clever man to distinguish himself in several sciences, and Brongniart became attracted to the study of minerals. Probably on this account, he was appointed Director of the Porcelain Factory of the French Government at Sèvres. But he became quite as famous for his work on fossil shells as for his additions to mineralogy.

After years of observation together in the field and in the museum, the two friends began to publish their results in 1808. In 1811, when politicians and soldiers were filling Spain with carnage, and were already planning the ruinous advance on Moscow, Cuvier and Brongniart issued a history of the peaceful ground of Paris, as it was before man

appeared upon its surface. Napoleon had appointed Cuvier Inspector of Public Instruction, and he continued to serve his adopted country after the downfall of the empire in 1815. In spite of his official duties, he brought out with Brongniart in 1822 an enlarged edition of the *Description géologique des environs de Paris.* With its coloured geological map on the scale of 1 : 200,000 (about one inch to three miles), and its plates of characteristic fossils, lithographed at Sèvres, this book remains one of the finest memoirs on any European district. The authors wrote with caution, for they were putting forward new opinions. They came to the conclusion that the sea had twice invaded the Parisian area since the deposition of the white limestone known as Chalk. Each time, on the withdrawal of its waters, the new land-surface had become exposed to the attacks of rain and rivers and other weathering agents, and hills and valleys had been formed. Lakes of fresh water meanwhile gathered in the hollows of the land. The second of the invading seas laid down a stratum of marine sand, which ultimately appeared as a great plain. Out of this, said Cuvier and Brongniart, the existing features had been carved, probably by rivers of greater force than those now running in the basin of the Seine.

The authors thus set before the inhabitants of

Paris the wonderful changes that had taken place in a very familiar piece of country. Lamarck, as we have mentioned, had already made known the great beauty of the fossil shells that could be gathered near the city. Cuvier and Brongniart, so far as we can judge, were not acquainted with the work of William Smith; but they showed independently how the shells of Paris marked out the successive deposits, so that the strata, on Smith's principles, could be recognized by the fossils that they contained.

It needed, however, further work, and work of a very detailed kind, to give us the full meaning and history of these beds of fossil shells. Two men, Lyell and Deshayes, were brought together through their keen scientific tastes; and they also reaped a rich harvest from the fossils of the Paris basin.

3. Charles Lyell begins his Travels

Charles Lyell came of a Forfarshire family, and was sent to study at the University of Oxford. Here, like most young men of his time, he pursued a course of reading in the classical authors of Rome and Greece. Even at the present day, we know that there are many people who honestly consider the knowledge of Greek and Latin literature in the original tongues to be the highest form of education. Young Lyell, however, had already collected butter-

flies; and the observation of their characters gave him a liking for natural history. Luckily for him, the Rev. William Buckland had been appointed Reader in Geology at Oxford. Geology was then quite a new subject as a university study. Men who entered on it became mixed up in all sorts of discussions which had little to do with the serious examination of the earth. Buckland was a man of genial character, and expressed his sentiments with a good deal of humorous vigour. He was not the sort of man to sit in an arm-chair and think out how the world might possibly have been constructed. He walked, rode, or drove about to see nature for himself, and collected specimens with a healthy energy that delighted and astonished his acquaintances. Most of us know the coiled fossil shells styled ammonites (Fig. 8, p. 30), which are found of such a large size in the Cotteswold area. Buckland came riding home on one occasion with a great ammonite, which had lost its centre, hung round his body like a French horn, his head and one shoulder sticking out above it. The naturalist Sowerby, who described the species, named it *Ammonites Bucklandi* after this adventure.

Lyell gladly found time to attend Buckland's lectures, and he soon saw that there were some points on which he must differ from his master. A school of geologists had already grown up in Scotland under

the influence of James Hutton, who read a paper on his "Theory of the Earth" before the Royal Society of Edinburgh in 1785, and published a famous book on the subject ten years later. Hutton laid great stress on the power of rain, frost, rivers, and so forth, to mould and alter the earth's surface. The agents now at work round about us seemed to him sufficient to account for mountains, valleys, and the beds of gravel that lie strewn in plains. Valleys, said Hutton, are not huge cracks caused by earthquakes, but are slowly carved out by the rivers that run in them. Year by year the hills are becoming lower, and all projecting masses are becoming worn down towards the level of the sea. Hutton suggested that great and perhaps sudden upheavals then occurred, bringing up new land to be attacked; and thus the whole process of wearing down would begin over again.

But most of the early workers in geology thought this far too slow a matter. They preferred to believe that the banks of gravel had been swept into position during deluges. When they saw blocks of granite cumbering some ravine among the mountains, they pictured the opening of a huge crack, and the rending of the rocks by the ruinous stresses of an earthquake. Buckland was one of those who took a vigorous view of the forces of the earth. Even the sudden upheavals suggested

by Hutton were not enough to satisfy him. A new science was being founded, and ideas that seem extravagant to us were then quite natural. Buckland and his friends felt that they must hurry up the agents pointed out by Hutton. They attracted attention, indeed, to geology by picturing the earth as a sort of bomb-shell whirling round in space, always ready to behave badly and to destroy its own surface, together with the living things upon it. A reign of comparative peace, however, seemed to have set in since man became settled on this surface.

Young Charles Lyell no doubt learnt much from the enthusiasm of Buckland; but he was already well convinced that one thing was necessary above all others for a geologist. "We must preach up travelling," he writes in 1829, "as the first, second, and third requisites for a modern geologist." He fortunately was provided with money, and his career gives us another example of a man using his time well, because he felt the call to think and work. He visited Switzerland and the French glaciers at Chamonix with his father and mother before he was twenty-three, and he kept a diary that shows how he noticed both the plants and the rocks around him. All kinds of small details are recorded by him; but this must always occur in diaries. If we note down just what we observe—a rock-feature at an angle of the road, a peasant clearing

his field from fallen stones, the effect of light and shade, or of new snow on the ledges, in bringing out the structure of some distant hill—we can select what we want, when we come home, from the notes written in each halting-place. We shall then never forget the impression made on us by contact with a new country, because we have set down promptly and truly all that has struck us on the way.

If Charles Lyell was right in insisting upon travel, his words can be acted on quite easily nowadays. Most people can save up money enough for a quiet holiday in the country, and those to whom geology proves attractive can choose some village as a centre, from which they can see strata with William Smith, or some mountain-glen where they can study the making and unmaking of the rocks with Hutton. As for the Continent of Europe, when once the plunge of a return-ticket has been taken, it is often cheaper to live abroad, and an extra week away may then make little difference. Some beautiful places, indeed, through the growth of specially conducted tours and steamer-parties, have become too much overrun with visitors. The organizers of those tours say, in effect, "If you will produce the money, we will count the change, speak the languages, and do everything that demands the least exercise of the brain." For those who have

youth and energy, this is hardly an intelligent way of travelling, whether one's taste lies in art, history, or in natural science. There is plenty of adventure left for the young man or woman of very moderate means, who starts one day from London by the express service, and wakes up next morning in central Europe, prepared to walk or cycle over the old historic ground.

Things were very different in 1829, when it cost Lyell a serious sum, and much bodily inconvenience, to travel from his home in Forfarshire to London. In February of that year, he tells his sister how he has just arrived by coach in Paris from Geneva, "four days and four nights, having only had six hours' rest at Dijon. Sledges for forty miles over deep snow on the Jura, and ice the rest of the way, so we were continually summoned by the conductor to turn out of the warm inside, while the horses tried to pull the diligence up." But in this way geologists at least learnt to appreciate the features and structure of the country. Lyell's first intent was to see for himself what others had described; and in this old-fashioned travelling he became able to compare the strata and the scenery, not only of Sicily and Scotland, but of every district in between.

Lyell's sight became weak in his youth, and he was unable to make detailed observations. But he

kept the large facts of nature before his mind, and gathered up every argument to show that, in trying to explain the past, we must learn at the outset what is now going on upon the earth. Another thinker, von Hoff, was working on the same free lines in Germany. Both men broke away from those who required gigantic floods, or vast and sudden upheavals of the ground, to account for what is written in the long record of the rocks. Both men looked to the action of existing causes to change the surface and to alter a whole continent in the course of time. Lyell in this went farther even than Hutton, and very soon rejected the catastrophes that satisfied his master, Buckland.

Are we wandering too far from the shell-beds of the Paris basin? Not in reality, for we must try to form a picture of the times, and of the way in which men went about their work. Fossil shells were among the things that attracted young Lyell into Italy. H. G. Bronn, the son of a forester in the Baden hills, had set out to study these shells some five years earlier, and became Professor of Zoology in his university of Heidelberg at the early age of twenty-eight, and finally one of the most eminent zoologists in Germany. A great deal of material, moreover, had been gathered for comparison with the beds near Paris by G. B. Brocchi, the Professor of Natural History at Brescia,

who published a book on the Italian strata in 1814. The results still needed bringing into order, and this work needed Lyell and Deshayes.

4. Lyell and Deshayes classify the Tertiary Strata

P. G. Deshayes, like Brongniart, was led towards zoology through medicine. He was a young Parisian doctor, who chose to be a tutor, in order that he might devote his leisure to research. He studied the fossil shells round Paris with great detail, so as to compare them with those living in our modern seas. His collection became famous, and Lyell sought his help as soon as possible. At that time, Lyell, when only about thirty years of age, was preparing his great work entitled *Principles of Geology*, the first volume of which appeared in 1830. This book, like Hutton's, sought to explain what we find in the rocks from what we know to be going on round about us. It led thousands of readers to look for the first time at the country as they travelled, in order to understand how "the mountain falling fadeth away, and the rock is removed out of its place." In his third volume, issued in 1833, Lyell frequently brings in the name of Deshayes, as an authority in the determination of the species of fossil shells; and he publishes elaborate tables, drawn up by his Parisian

friend, to show how certain beds contain few species that are now living, while other beds, deposited in

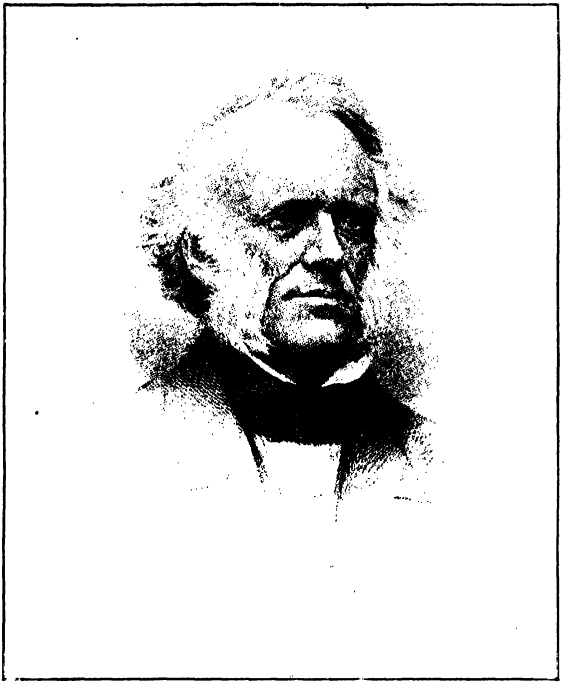

FIG. 15.—Sir Charles Lyell, F.R.S., about 1870.

later times, contain a much larger proportion of shells like those of the present day.

Lyell met Deshayes in 1829, and was drawn cordially towards him, styling him "the Cuvier of tertiary shells," and "the strongest fossil con-

chologist in Europe." The strata overlying the white chalk had never been properly classified, and Deshayes and Lyell had independently resolved that this must be done by means of the fossil shells of molluscs that were so abundant in them. They soon found that, as we work backwards into the past history of the earth, these shells become more and more unlike those with which we are familiar. Strata could not only be recognized, as Smith had shown, by the animal remains in them, but the details of the forms of the shells were found to have changed in a regular fashion as they were traced into older periods.

Lyell and Deshayes thus gave a new interest to the work of William Smith, and unconsciously opened up the way for those who maintained that animal species show a continuous development from ancient times to the present day. Lyell records that Deshayes compared nearly forty thousand specimens with one another in order to construct his tables. To-day we can discuss the results of his labours in a few approving lines. It is easy for us to reap what was sown with such patience and such loving care. Work of this kind requires keenness, as well as the mere power to persevere. Lyell and Deshayes were two young enthusiasts, who saw that all these detailed observations were necessary, if the truth was to be found out. As a

result, three great geological periods were marked out by them between the time of the formation of the Chalk and the present day. It was like the discovery of three ancient cities, one below another, and each rich in records of a forgotten race.

These later strata of the earth's history were generally spoken of as Tertiary. Lyell divided up the Tertiary group into three systems, using names that are now recognized throughout the world. He found that in Sicily there were uplifted marine beds in which ninety-five out of every hundred species of shell-fish can be matched in modern seas. These he called "Newer Pliocene," or "newer more recent" strata. Earlier than these, he found an "Older Pliocene" series, with about half of its shell-fish still living on unchanged. Before this was the "Miocene" or "less recent" period, with only eighteen per cent of living molluscan species, and before this the "Eocene" period, or "dawn of the recent," a time so remote from our own that only three and a half per cent of the species are still with us.

Later workers have found it useful to insert an "Oligocene" period, meaning "with few recent shells," between the Eocene and the Miocene; most of the beds included in it formed part of Lyell's Eocene. Miocene, Oligocene, and Eocene strata have been carefully mapped out round Paris; but

this region became dry land before the end of the Miocene period. Hence the Pliocene system remains best known to us from Italy, a country that has risen above the sea in very recent geological times. The "Crag" beds of Suffolk and Norfolk, so named by William Smith, are, however, of Pliocene age, and shells can be picked out from the sand-pits in them almost as easily as from a modern beach.

The laborious and successful work of Deshayes has been highly useful in classifying our English strata. We have no Miocene beds, and our region must have remained at that time above the sea. We have not even the lake-deposits that form so much of the Miocene strata in France and Switzerland. Oligocene beds, marine and freshwater, occur in southern Hampshire and in the northern half of the Isle of Wight. London is built on Eocene strata, which spread away from it north and south and west, and give us the clays and sands overlying the chalk, which we mentioned when we travelled with William Smith over the English highways. Among these beds are the stiff brick-clays, Smith's "London Clay," and the level forest-covered sands of Bagshot Heath. By comparing our fossils with those of Paris, we know the geological history of south-east England.

Charles Lyell had money behind him, and, as a

lecturer and a writer, was able to attract the most cultivated men and women in London. Of course, he called on Cuvier when in Paris; but he found that the great man preferred by this time to talk of politics rather than of natural history. Yet Cuvier's industry was undiminished. His public career had brought him rich honours in spite of every change of government. He must have originally learnt from Bonaparte the art of laying out his day, so that he could carry forward several schemes at once. Lyell tells us how Cuvier worked, in a suite of rooms connected with his dwelling-house :—

"When he is engaged on such works as require continual reference to a variety of authors, he has a stove shifted into one of these rooms, in which everything on that subject is systematically arranged, so that in the same work he often takes the round of many apartments. But the ordinary studio contains no bookshelves. It is a longish room, comfortably furnished, lighted from above, and furnished with eleven desks to stand to, and two low tables, like a public office for so many clerks. But it is all for one man, who multiplies himself as author, and admitting no one into this room, moves as he finds necessary, or as fancy inclines him, from one occupation to another. Each desk is furnished with a complete establishment of inkstand, pens, etc.,

pins to pin MSS. together, the works immediately in reading and the MS. in hand, and on the shelves behind all the MSS. of the same work. . . . The collaborateurs are not numerous, but always chosen well. They save him every mechanical labour, find references, etc., are rarely admitted to the study, receive orders, and speak not."

Cuvier died as a peer of France in 1832.

Lyell, however, found Deshayes far more congenial. Deshayes earned money where he could, writing articles, teaching privately, and was always ready to spend it again on research. He published his work on the Parisian molluscs largely at his own cost. Lyell wrote of him in 1835, "he must work hard the whole year to preserve his independence." And this hard work was, we are glad to think, understood by his intelligent countrymen during his long and active life. The great and permanent value of the association of Deshayes and Lyell is that they showed us how the story of the rocks is connected, link by link, with our own human times.

CHAPTER V

RUNNING WATER

1. A River and its Valley

Rivers appear before the eye of man in many different aspects. The dweller in the plains sees a broad band of gently flowing water, curving this

Fig. 16.—River meandering in an Alluvial Flat, Laramie Basin, Wyoming. (From *Bull. U.S. Geol. Surv.*, No. 364, 1909.)

way and that like a serpent across the lowland, and reflecting in its smooth surface the expanse of sunlit sky. Now and again he may notice clouds

gathering against the far-off ranges of serrated hills in which the water takes its rise. It is raining away yonder, and in time the placid stream will begin to climb against its banks. It will also flow more swiftly, because of the head of water suddenly flung down into its upper reaches. It may become discoloured by brown mud swept off the uplands, and even fine sand is borne along, with tiny flakes of mica that turn and glisten in the sunlight. Slabs of rock, and grassy islets well known to us in the lowland, become hidden in the rising stream, and perhaps it even spreads across its banks and surrounds the stems of trees upon its margins.

The farmer of old times, or the new and observant settler, has planted his house upon higher ground, just as you may see farms elevated on knolls throughout the east of Holland. In this he does well for his own safety. After the storm has raged away up yonder, the hills stand out clearly again, with perhaps a touch of snow in their high hollows; but the flood-water still comes down, spreading over the fields, and driving even the cattle off the lower grounds. Days may pass before it subsides again, leaving a layer of fine mud over the lowland, and a film of coarser matter along its banks, where it began to overflow. We see that it has built up in the course of time a sort of low wall or causeway along its margins, through the deposits of successive

floods; the water could not carry the coarser sand farther when its flow was checked against the fields. This wall-building through river-action is a source of considerable danger in some great plains and deltas. The river rises on its own deposits, and, when a breach occurs in the alluvial wall, the flood descends with a devastating rush over the lowland. The material of various kinds laid down by the river is styled *alluvium* (Figs. 16 and 19).

The scene is very different if we visit those far-off hills on which the rain and snow so often fall. Here we see a stream, perhaps only a tributary of the main one, emerging from a narrow gorge. It is difficult to find a track along which we can safely clamber up beside it. The goats have worn a few paths on the steep banks, but even these have to climb high in places to avoid jutting rocks and vertical cliff-walls (Fig. 17). The water hurries along beneath us, as we look down into the ravine, and it evidently carries stones and sand along with it. Where it escapes into the plain, it has heaped up a great cone of pebbles, over which it flows in several branches towards the lowland. All these pebbles, like the sand and mud deposited in flood-time farther down, must have come from the highlands on the threshold of which we now are standing (Fig. 19, p. 74).

A little farther on we come to a true waterfall.

The beds of rock in the sides of the ravine are seen to be uptilted, and some of them stand out like ribs, while others crumble and fall away. One of the most resisting ribs has here formed a steep front,

FIG. 17.—Gorge of the Romanche above Le Clopier, Hautes Alpes. (G. Cole photo.)

over which the whole stream falls. At the foot of the fall, the water has churned out a great pot-hole in the beds below. Sand and stones get swept into this, and only serve as tools to cut it deeper. The water plunges into the hole, and flows out,

foaming with huge bubbles, over its outer lip. Above the waterfall, the stream is calmer, and has even laid down a stretch of sand, on which rough grasses grow.

Higher up still, after this easier piece of walking, we come to another waterfall. Here considerable blocks of rock have broken from the crest, and cumber the foot of the fall. As this goes on, the face over which the water drops must become lower. May not a time arrive when the rock will be so broken away as to give a mere slope of boulders instead of a steep wall? The waterfall will then become a torrent. As the boulders themselves get worn away, the river will flow over a fairly gentle rocky floor. The traveller who comes after us, say even in a thousand years or so, may find no traces of the waterfall.

Thus, by a series of steps, from one platform of the valley to another, we approach the true source of the stream. Here it really consists of many streamlets, spreading away up side-valleys which are arranged like the bars of an opened fan. The cone of gravel piled on the lowland gave us the opposite effect, for there the river broke into radiating branches as it ran downwards over the cone.

Each of the streamlets lies in a groove, the sides of which are continually being undermined and falling in. Higher up still, we find that these

streamlets have no very clear beginnings. They represent the union of a great number of trickling waters which flow in and even beneath the soil, and they are fed by the rain and the dew, and the snows of winter, which are deposited on the upper regions of the mountain-chain.

As we came up the gorge, we noticed the same rocks on either side, just as if the mountain-slope had been cut through with a knife. But at the waterfalls we came across the solid rock, extending as an unbroken barrier across the valley. Hence the valley cannot be due to a crack in the ground, along which the water has found its way. Even if it started in such a crack, it must have become widened, just as we see the little tributary valleys on the highland growing wider as their walls become undermined. Surely the river itself, with the stones and sand as tools provided for it, has worn out its valley, and is deepening it still, wherever the slope allows it to run briskly.

2. How the Valley changes as it grows

This conclusion may seem clear to us in the place chosen for our study; but it requires some courage to apply it to the great valleys of the world. Rarely, indeed, do we see a change in the rocky part of the river-bed. A block falls in here and there from the walls; but it will take a long

time for the water to wear the obstacle away. The lip of the barrier at the waterfall is smoothed and rounded; but we may sit by its edge day after day, and yet see no visible lump of rock detached from it.

Indeed, it seems as if cracks must have occurred in some cases, into which the rivers found their way. This was a general opinion among older geological observers. It is quite true that streams follow down cracks if they can find them. They may be seen, for instance, on granite mountains, disappearing at times in the shrinkage-cracks that developed in the granite as it cooled (Fig. 18). Among limestones, or those very hard sandstones known as quartzites, there are conspicuous joints, and the running water naturally takes advantage of them. In the case of the limestone, the water, containing carbon dioxide from the atmosphere, can actually dissolve the rock. The joint becomes thus readily enlarged into a ravine. In quartzites, streams would find it very difficult to make a channel, were it not for the cracks that lie ready in the rock. The water enlarges these cracks, by washing away blocks from their walls, and these blocks serve as tools for further action. Ravines arise in quartzite, even in wet countries, since the rain wears away the sides of the cracks less quickly than the river can work its groove down into the ground.

The same is true of limestone, which absorbs much of the rain that falls on its surface, and is thus saved from being washed away. Some of the

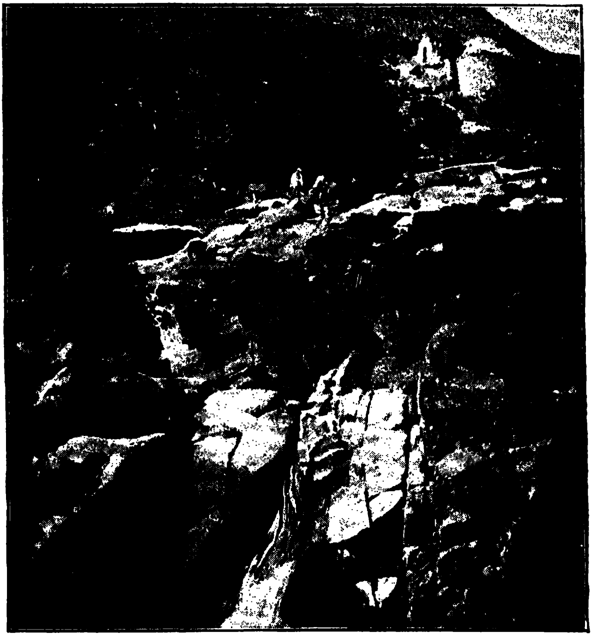

FIG. 18.—River finding its way along joints in granite, slope of Slieve Donard, Mourne Mountains. (G. Cole photo.)

grandest steep-sided valleys in the world have been formed in limestone. On the other hand, in most valleys the sides are being moulded by frost-action and by the wash of rain during the long period that the river is at work. Hence the walls become

cut back, and the valley-sides become covered with huge banks of stones, which sometimes tend to slide out and to choke the stream. When we see the great hollow thus carved out, we can hardly believe that it had its origin in the narrow band of water that we see flowing in its depths. We want to look for some larger cause to do the work more quickly.

When geologists were forced to admit that gigantic rifts had not opened in the earth, the sides of which, falling apart, formed the present walls of our great valleys, they then took to the idea of destructive floods, which were supposed to have swept across the mountains once for all. Observers, however, of causes now in action pointed out, as Shakespeare says, that huge stones waste with little water-drops. "Give us time," they said, "and you will see the insignificant river make for itself a way across the hills."

Among these men were the profound thinker James Hutton, of Edinburgh, and his follower Playfair, who believed so strongly and so justly that even the large features of our scenery can be explained by the action of forces which now work round us on the surface. Cuvier and De Saussure, on the other hand, who were so distinguished for their observations in other branches of geology, held that the sea had cut out many valleys as the

land rose from the ocean-floor. They seem to have thought little of the views of the French predecessor of Hutton, Jean Etienne Guettard, who had travelled widely in Europe, and who clearly explained the action of running water so far back as 1774.

John Playfair, writing in support of Hutton in 1802, quotes from his master the principle that "the rivers have, in general, hollowed out their valleys." He then points out how land uplifted from the sea would have an irregular surface, over which natural waters would have to make their way. A waterfall would occur at one point, a lake-basin at another. But Playfair showed how these lakes are only temporary features. The stream, as it runs out of a lake in the valley-floor, deepens its outlet and allows the lake to drain away. The waterfall-region thus cuts its way back into the lake-region. At the same time, the material brought down from the upper part of the valley tends to fill up the head of the lake. These actions work together, until the waterfalls have cut through the barriers that caused them, and a long and almost uniform slope has been given to the valley-floor. This slope is known to be steeper in the higher levels of the hills, where the active denudation of the rocks tends to produce vertical forms; and it curves away gently to the plains,

and so to the sea-level which is sought by almost all our streams.

3. The Destruction of the Hills

But, as Guettard and Hutton clearly saw, this

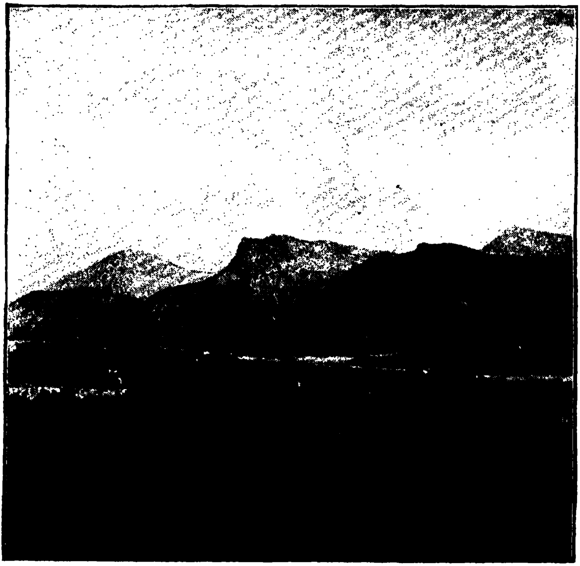

Fig. 19.—Highland dissected by streams, which emerge on a main valley with alluvial terraces. Valley of the Durance, near Remollon, Hautes Alpes. (G. Cole photo.)

carving away of the highlands must ultimately check the streams. Their cutting power depends upon their volume and on the slope of the valley-floor. As the highlands become dissected

by innumerable streamlets, the supply of water dwindles. The gathering-ground of the snow and rain is becoming lower every day. The stream-bed, moreover, is becoming adapted to the stream. The waterfalls are disappearing, the torrents are growing less vigorous as they wear away their sloping floors. Out in the lowland, excavation has ceased long ago, since the ground has been lowered practically to the level of the sea.

The action of the rivers is aided enormously by frosts, which break up the surface, and by rains, which sweep the loosened particles away. In the broader parts of its valley, the stream, swinging sluggishly from side to side, none the less undermines the bounding walls, and spreads the level land at the expense of the diminishing hills. The total effect is to wear down the hills to a mere plain, on which the remaining streams meander. A few blocks are left upstanding, and denudation now works on these alone. The plain may become dry, through the destruction of the highlands, which once forced the winds upwards till their saturation level was reached (see p. 103). Yet even now the dust that is swirled up against the outstanding bluffs will serve to wear them away. Unless something comes to the rescue, these last remnants of a picturesque and varied region will ultimately pass out of existence.

Hard and soft rocks alike, rocks soluble in rain-water and those that stubbornly resist chemical attack, thus perish before the action of the waters

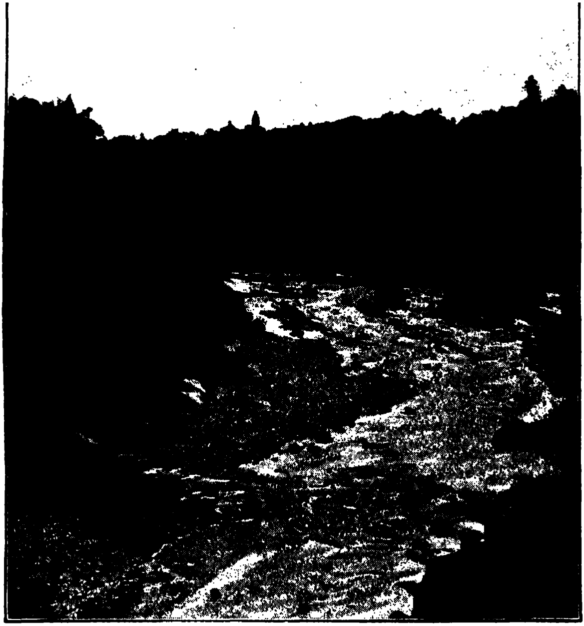

FIG. 20.—Stream working sideways at its bank, and leaving pebbly alluvium on the other side of the bend (left-hand side of picture). R. Esk, near Canonbie, Dumfriesshire. (G. Cole photo.)

condensed out of the atmosphere, or before the winds that blow. Where glaciers occur, the effects are locally intensified. Larger blocks are in that case carried away from the mountains to the plains. The rock-dust of all these worn-down masses finds

its resting-place ultimately in the sea. Prof. W. Morris Davis, whose writings on physical geography are so well known to most of us, has called the

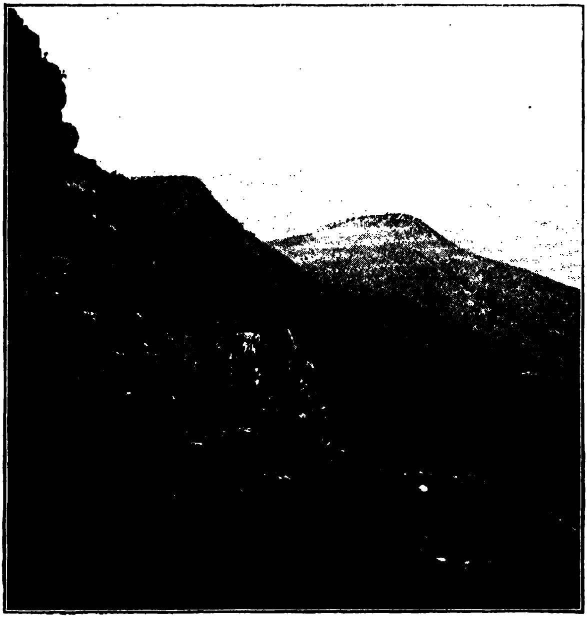

FIG. 21.—Edge of the Uplifted Peneplane of the Transvaal, S. Africa, at the Duivels Kantoor, west of Barberton. (G. Cole photo.)

plain that results from prolonged rock-wasting a *peneplain*, "almost a plain." It can rarely be a perfect plain, for a few ribs and bosses of rock will remain above its general surface. Some people prefer to write this useful word as *peneplane*. A

peneplane may cut uniformly right across all manner of folded and complex structures underneath.

When the peneplane has been established, waste and erosion cease, except by solution of the surface. Directly, however, it is lifted up by earth-movement, it becomes dissected and is made young again, and picturesque forms due to unequal weathering stand out once more upon its surface (Fig. 21).

The idea of the wearing down of a whole country to its lowest possible level, that of the sea, had been made familiar by Guettard and Montlosier in France, and by Hutton in the British Isles. But it is only in the last thirty years that people in general have been willing to accept it as an explanation of the land-forms that we see. Here the work of American geographers has been of immense help to all of us. No one nation can claim that an advance in science has been theirs alone.

4. Rivers and Earth-Rifts

The course of the Rhine from Bâle for a long way northward lies in a broad groove between the Black Forest and the Vosges, and the floor of this groove has been lowered along a number of parallel cracks in the earth's crust. So we must not abandon the old view that river-valleys may be

connected with earth-fracture. Not suddenly, but very slowly, regions may be let down in this way from their original level, and become natural receptacles for lakes and river-courses. Such valleys, moulded but not actually cut out by the streams, have been called "rift-valleys" by many writers.

In other cases, as we have already hinted, the prevailing cracks in the rocks determine the direction of the river. The most striking instance of this kind occurs in the course of the Zambezi. The Victoria Falls on this river have now become the most famous in the world. Though other cataracts occur nearer the coast, it is quite possible that Daniel Defoe refers to them in his excellent geographical romance of *Captain Singleton.* Portuguese traders may have got news of them from natives who came down from the far Batoka country; and Defoe, as we know well, learnt many a true report along the quays of London. Singleton is made to say that his party of adventurers, in their first crossing of Africa, were stopped by "a great waterfall or cataract, enough to fright us, for I believe the whole body of water fell at once perpendicularly down a precipice above sixty foot high, which made noise enough to deprive men of their hearing, and we heard it above ten miles before we came to it."

The Victoria Falls were estimated by David

Livingstone, their white discoverer, on his first visit, to be about 100 feet in height. The roar of the water, and the spray that rises at times 1000 feet in the air, are recorded in the fine native name, Mosi-oa-tunya, "Smoke sounds there." Livingstone, who had the enthusiasm and energy of a true explorer, got himself taken in 1855 in a native canoe to the island in the centre of the falls, and thence looked down into the abyss. He observed the extraordinary drop of the whole river into what looked like a crack recently opened in the earth, and he recognized that the dark rock in the cleft was basalt. The narrow gorge below the falls runs in a zigzag course for forty miles across the country, and Livingstone gained a clearer idea of it on his second visit five years later. He measured the drop this time with a line, of which he paid out 310 feet, leaving, as he judged, about 50 feet still between its end and the foaming water. This result was remarkably accurate, for the cliff is now known to be about 380 feet in height. The river above the falls is about a mile and a quarter wide, and presents no dangers to a skilled native boatman when the water is not in flood. At the falls, however, it descends into a ravine in the stratified basaltic lavas, and this cleft is only some 250 feet in width.

It is no wonder that Livingstone saw in the

immense line of falls signs that the earth had broken open; and this idea has been repeated, even in an official guide-book, down to our own day. Sir Archibald Geikie, however, only a few years after Livingstone's visit, stated his belief that the Zambezi River had cut out its own gorge; and he suggested that the water had been turned aside so as to fall over the side, instead of into the end of its ravine. The theory of a great crack, however, held its own. Certainly there is something amazing in the scene, when one looks along the mile or more of waterfalls from either end, and realizes that all this flood is being carried away by a narrow channel at right angles to that into which it thunders down. The spot is now easily accessible by the Cape to Cairo Railway, which crosses, on the highest arch in the world, the ravine through which the water runs away.

In 1905, Mr. A. J. C. Molyneux of Bulawayo, who knew the district through older means of travel, published a complete account and a convincing explanation of the falls. He showed how the vertical joint-cracks in the basaltic rocks had determined the strange and zigzag bendings of the stream. He traced how the river had cut its way back in this hard rock from point to point for forty miles, abandoning old channels at times for new ones, and leaving the notches worn by former

waterfalls high and dry upon its walls. In the same year, Mr. G. W. Lamplugh, of the British Geological Survey, aided by Mr. F. W. Sykes and Colonel F. W. Rhodes, explored the valley for

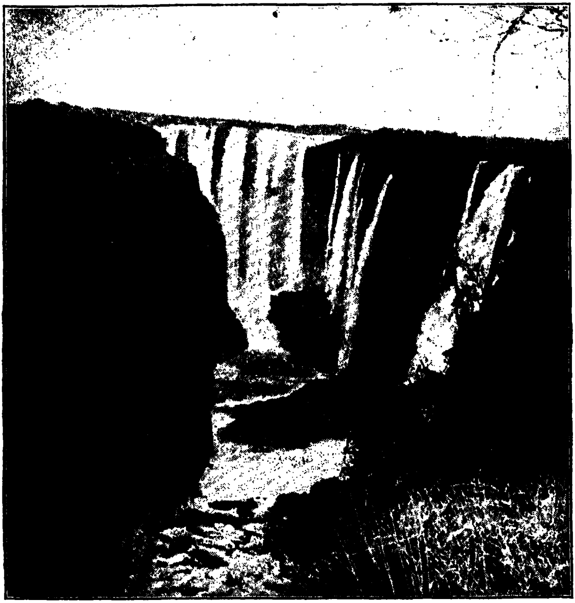

FIG. 22.—View along the Chasm of the Victoria Falls, Rhodesia, from the northern end. The outlet is in the centre on the left. (G. Cole photo.)

a distance of seventy-five miles east of the Victoria Falls, and became convinced that the features of the ravine were due to river-action. He showed how faults (p. 176) here and there made lines of

weakness that influenced the torrent's course; and he explained the great chasm at the falls as resulting from the washing away of a band of soft decomposed rock and crystalline carbonate of lime that had formed along a similar crack in the crust. So, after all, if river-action has cut the ravine, the structure of the crust has had much to do with its direction and its extraordinary features.

Sitting on the edge of the Rain Forest, so called because of the spray that is continually condensed upon its leaves, one looks across at the falls, pouring over the rock-face opposite, 380 feet down into the gulf. When the water is low, after the rains have run off the upper country, the broad flood of the Zambezi above the falls divides itself into a number of channels, some wide, some narrow, on the actual lip of the ravine. The channel nearest to the south end, occupied by the cascade called Leaping Water, has clearly been cut down more deeply than the rest. As Mr. Lamplugh shows us, the low-water season is the time to study the action of the stream. Should this notch and others near it, some of which are only occupied at high water, become further deepened, more rapidly than those on the main lip of the falls, the whole body of water will be drawn off to this end of the chasm, and the northern half, beyond the outlet, will become a dry ravine. A new

angular bend will be given to the Zambezi; and other winding channels are doubtless being prepared in the unseen river-floor above the falls.

The zigzag course of the river below the falls,

Fig. 23.—The Zambezi above the Victoria Falls. The edge of the falls is in the distance. (G. Cole photo.)

in a ravine that increases from 400 feet to 800 feet in depth, is thus explained by the cracks in the basalts on which we sit and view the scene. One series of joints runs into the Rain Forest

land behind us; the other runs parallel with the precipice beneath our feet. Both sets are excellently seen from the north end of the falls, as one looks along the eastern wall. As we peer over from

FIG. 24.—The Edge of the Victoria Falls, Zambezi River, Rhodesia. (G. Cole photo.)

the edge of the Rain Forest, we see the cataracts plunging down here and there behind upstanding walls parallel with the main wall. These walls are relics of the former face of the great cliff; the water is now working into the next

prominent joint a little farther back. The falls have already receded, through rocks of various kinds, six hundred miles westward from the spot over which they plunged in far-away geological times. They are now near the village appropriately named Livingstone, merely because in our day they have notched back the African plateau to this particular point. Every year, little by little, the calm sweep of the Zambezi above the falls is being shortened by the creeping backwards of the fierce and angry portion of its course. No grander contrast in river-features can be imagined than that obtainable from a boat above the falls. We are paddled by trusty Batoka men to the island visited by Livingstone in the centre of the stream. A few minutes of trampling through the bush bring us to the bare rock-edge where the water plunges sheer. Standing here in perfect safety, we see this mile of water disappear, as it were, into the earth. On the opposite side, across the spray-clouds and the rainbows, the level land continues, covered with scrub and scattered trees. The Zambezi in that country eventually drops 1000 feet below us, in the channel that its energy has carved.

5. How fast does a River work?

We have already said that we must not expect to see a river cutting away its bed before our eyes.

But in some cases the softness or the structure of the rocks enables us to see rapid changes. We all know how the swirl of a stream in flood will undermine its banks, and cause broad masses to fall in on the concave or invaded bank of its meanders. In this way a serpentine bend shifts its position downstream, while pebbles and sand are left stranded on the opposite side of the bend, where the bank bulges out convexly towards the water (Fig. 20).

Sometimes, again, a sudden burst of rain causes torrents that sweep down over slopes covered with soil or gravel or decaying rock, and thus work out in an hour or so very conspicuous grooves. But it is more profitable to see if we can measure the effect of a river on solid rock.

Lyell long ago tried to do this in the case of the famous Niagara River. The gorge has been cut back six miles from the cliff-face at Queenston on Lake Ontario, and the great falls, which originally descended over this cliff, are always receding towards Lake Erie. The rocks through which they are cutting consist of a massive shelf of limestone above, and of shale below. The spray eats away the shale, and blocks of limestone fall into the ravine. Hence the recession is irregular, but somewhat rapid; and Lyell, and Canadian observers before him, saw that it might be measured through a long period of time. Owing to the amount of

water now drawn off for industrial purposes from above the falls, both the Canadian and the United States Governments determined to make a complete survey before 1905, after which the conditions of flow would unfortunately cease to be natural. The

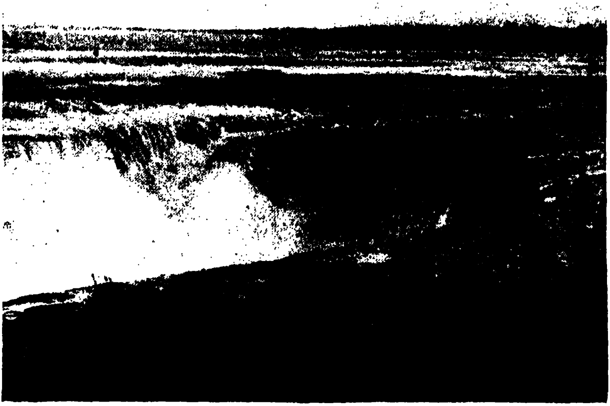

FIG. 25.—The Horseshoe at the head of the Niagara Gorge, about 1886. (From *Bull. U.S. Geol. Surv.*, No. 306, 1907.)

Horseshoe Fall is the true head of the gorge, and here the cutting action is fairly rapid (Fig. 25). Prof. G. K. Gilbert, reporting for the United States, believes that very little change took place between 1827 and 1842. From 1842 to 1875, the fall receded as much as 4 feet every year, and from 1875

to 1905 about 6 feet every year. The American Fall, on the other hand, probably recedes only two-tenths of a foot in a year. Even this figure is not so small as it looks, when we remember how nature works in thousands of years, while we reckon up our lives in simple years.

In soft ground, the cutting of streams is often startling. In the east of Jämtland, in central Sweden, lies the village of Ragunda, in an upland valley draining to the Gulf of Bothnia. Before 6th June, 1796, a long lake spread for some twelve miles up the valley, and, at its foot below Ragunda, discharged itself over a steep slope of crystalline rocks, cumbered with huge boulders, forming Storforsen, "the great waterfall," which was one of the finest in Sweden.

The lake originated, however, not in a rock-barrier, but in a natural dam of sand and loam, set down across the valley towards the close of the Great Ice Age (p. 117). Beyond this dam, and some 70 feet below the level of the lake's surface, lay a stretch of meadow-land. It had long been felt that a channel through the dam might allow of continuous traffic by water, which was impossible over the great fall at its north-east end.

An ingenious person, one Huss, appropriately nicknamed "Wild Huss," undertook in 1796 to cut the dam with the aid of a little stream that

already ran down on to it. Diverting this water, he made it cross the dam, and a connexion was worked back into the Ragunda Lake. No sooner, however, were the lake-waters set free across the loam than they cut down through it with terrific vigour. In a few hours the great lake drained tumultuously out by the new channel; the Storfors ran dry; and a deep trench was cut in the stratified deposits on which the lake had lain. The old river-course below these deposits, a course, in fact, older than the lake itself, became in part revealed. The site of the great waterfall is now a mass of bare and tumbled rocks, with pot-holes worn out by the swirl of stones and sand, showing how the river once thundered down upon them.

A similar catastrophe on a far bolder scale was brought about by human assistance on the Mexican border in 1905. The Colorado River, on leaving the country of uplifted plateaus and narrow gorges, runs over an immense alluvial cone to the Gulf of California. The growth of this cone cut off one hundred and fifty miles from the head of the long gulf, and the country above the barrier long ago became dry, in the warm air of a region where rain rarely falls. The floor of the arid country thus revealed lies in part 300 feet below the waters of the gulf, and a lake without an overflow channel, called the Salton Sink, occurs in it. This lake

varies in extent, according to the water that finds its way down into it. In former times, perhaps a thousand years ago, it occupied a large part of the basin.

The old sea-floor, in these days of enterprise, has attracted settlers from the United States and also from Mexico. The boundary of the two countries runs across it. Occasionally, part of the Colorado waters, spreading on the broad alluvial cone, has flowed down into the hollow, forming the Alamo and the New Rivers, which run into the Salton Sink. As a rule, however, the country is uncomfortably dry. Hence, about 1900, attempts were made to get some permanent benefit out of the Colorado. In May 1905, when a fair-sized channel of communication had been made, the river, in flood-time, swept away the lock-gates and poured itself down towards the Sink. The Salton Sink soon became the Salton Sea; the Southern Pacific Railroad was driven to choose a route farther from its margin; and the variable New River, now a foaming cataract, cut its way back through the old alluvium to the town of Calexico on the frontier. Calexico, by the by, is one of those American words that tell their own history, being a compound of California and Mexico.

At Calexico the stream cut a valley 45 feet deep through the agricultural land. The Mexican

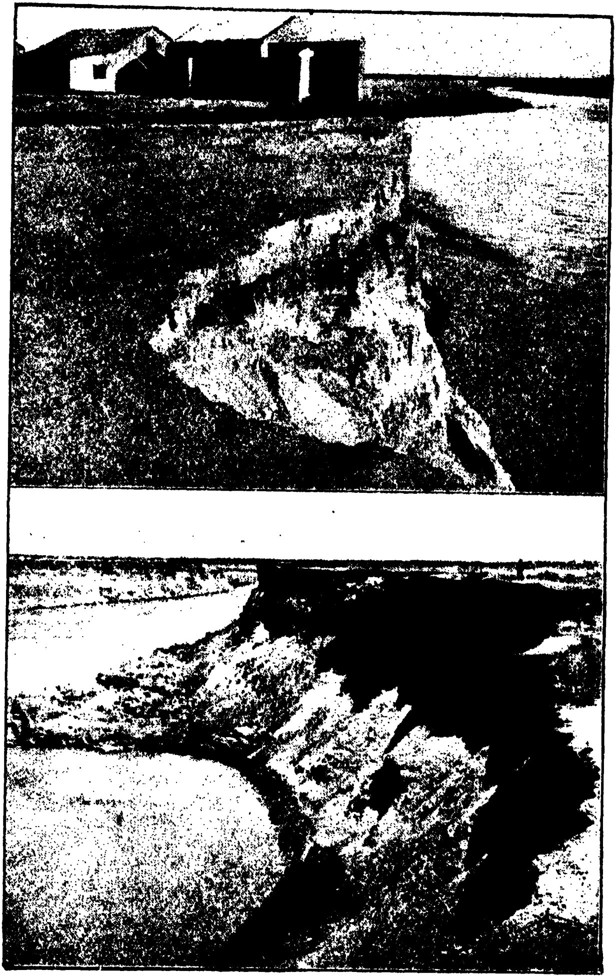

Fig. 26.—The New River cutting into the town of Mexicala (upper figure), and into farm-lands near Imperial, California (lower figure), forming banks 70 ft. in height. (From the *National Geographic Magazine*, 1907.)

town of Mexicala was partly carved away. The farmers who had wanted water now had too much of it; but it ran out of reach at the foot of treacherous and crumbling cliffs. Near Imperial in California, the new valley was soon 70 feet in depth. Heroic efforts were made to shut off the water on the alluvial upland; but at the beginning of 1907 the New River was still eating its way back southward at the rate of a mile in three days.

The Southern Pacific Railroad, however, as a much interested party, at last managed to close the gap early in 1907. The evaporation in this arid region is so great that the Salton Sea sank in a few months, until its surface was 200 feet below the level of the sea. It is estimated that the great lake will have disappeared by 1925. Meanwhile, its water, soaking into the old marine deposits, has become of service to farmers at a distance; and these will regret its disappearance, although others will seize upon the ground that again becomes left bare. The changes in the surface-features within the limits of two years are surely enough to make us believe in the efficiency of running water.

CHAPTER VI

SCRATCHES ON THE ROCKS

1. The Scratches are discovered

In many places we can see the soil in process of formation out of the solid rock. The soft powdery material at the surface, in which the worms burrow so easily, becomes more stony as we trace it down-

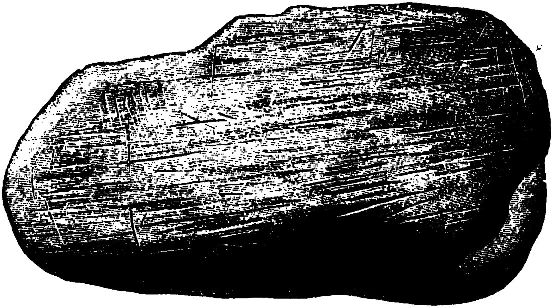

Fig. 27.—Boulder scratched by inclusion in Glacier-ice.

wards; and, if we dig still lower, we find the stones fitting against one another, separated only by cracks, and forming part of a rock-mass that has only just begun to fall asunder. But in other places we find an earthy or gravelly soil, full of pebbles or even boulders, resting on a smooth surface of solid rock, as if it had no connexion with

what lay below it. Many of the pebbles or boulders here have scratches on them, as though they had been scored by knives; in some cases one side has been ground and flattened, and shows the scratching very clearly. These are not stones that have been under the plough, nor have the strong farming men marched over them with hob-nailed boots. There may be 100 feet or more of what is called "boulder-clay" (see Fig. 5) before we get down to our smooth rock-surface; a sea-cliff or a deeply cut river-bank may be required to show us all we want to see. And then, if we clear away the loose material carefully, and lay bare a surface of the rock that no human eye has seen before, we shall discover scratches here also, and even grooves, running in some definite direction. These are best seen if we get a bucket of water and empty it on the surface, thereby washing away the last traces of the earth or sand (Fig. 28).

Such occurrences are not at all uncommon in the British Isles. In 1812, Sir James Hall called attention to examples in the neighbourhood of Edinburgh. "The surface," he writes, "is found to resemble that of a wet road, along which a number of heavy and irregular bodies have been recently dragged; indicating that every block that passed, and every one of its corners, had left its trace behind it; and these are rendered distinctly

visible, when the surface is drenched with water." He noted that the striations are fairly parallel, and explained them by supposing that huge floods had

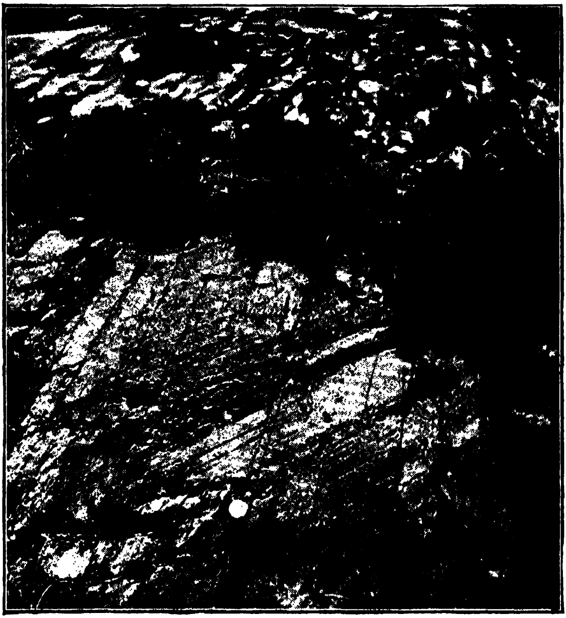

FIG. 28.—Rock-surface scratched and grooved by the movement of a glacier over it. Doo Lough, Co. Mayo. (From a photograph by Mr. T. Hallissy.)

dragged the stones and boulders over the land. Some of the largest blocks, he pointed out, might have been carried on rafts of ice during a time of wholesale desolation.

2. The First Explorers of the Alpine Snows

About the time that Sir James Hall wrote, similar and far more conspicuous scratches were being observed on the bare rocks of the great Swiss valleys. Horace Benedict de Saussure had led the way for a careful study of the Alps. Between 1779 and 1796, he published at Neuchâtel, which was then a dependency of Prussia, his great work in four volumes entitled *Voyages dans les Alpes.* In the eighteenth century, the snows of the higher Alps appeared very terrible to travellers who approached them. It was quite bad enough to be caught in a snow-storm, and rescued, however beautifully and touchingly, by the good monks of the Hospice of St. Bernard, aided by their warm and woolly dogs. The paths that then crossed the mountain-range were mule-tracks at the most, carried on wooden bridges across the streams, and sometimes passed along precipices merely with the support of beams driven into the walls of rock.

De Saussure waited many years before he found guides in the valleys near Geneva bold enough to attempt the summit of Mont Blanc. In 1760 and 1761 he offered a reward, and was even prepared to pay the expenses of those who tried unsuccessfully to find a way. One man made two expeditions, but returned hopeless.

Fifteen years passed, and then four guides from Chamonix ascended the lower slopes and climbed into a valley well above the snowline; but the brilliant sunlight, reflected from the gleaming surface of the snow, and the thinness of the air, made them suffer from heat and a desire to sit down and sleep. Eight years later, three other guides were defeated by the same sensations. M. Bourrit, a friend of De Saussure, learnt of a new route from certain chamois-hunters, who had climbed to an unusual height over spurs of rock; and the two observers set out together, with guides and porters, in 1785. They slept for the first night in a stone hut built beforehand, probably the earliest of the life-saving shelters which modern climbers now count on finding in the Alps. But the fresh snow lay too deeply on an upper portion of their route. They returned to the hut, and Mont Blanc was not climbed until August 1786.

In June of that year, Dr. Paccard and his guides made an attempt, in which they were joined by another guide, Jacques Balmat, whom they had not asked to be of the party, and who in consequence was kept somewhat aloof. Jacques Balmat, hanging behind, missed the party on the descent, and boldly spent the night out on the mountain, burying himself for shelter in the snow. Having plenty of time next morning, he walked about the

snowfield, and discovered a sure way to the crest. He kept his secret for a while, but in August he guided Dr. Paccard and his party successfully to the summit of Mont Blanc. The explorers had now the delight of standing more than 15,000 feet above the sea.

De Saussure started off next day; but bad weather stood in his way until a whole year had elapsed. Balmat, meanwhile, led two other guides to the top in July 1787. On 1st August, De Saussure set out with his own servant, Jacques Balmat and seventeen others, a formidable array of guides for one scientific climber. In the evening this company of strong men found it hard to excavate a shelter in the snows at a height where the barometer fell to below eighteen inches. De Saussure generously records the courage of his predecessors, Balmat and Paccard, who had proved that it was possible to survive a night on the upper levels of the mountain. Axes were used next morning to cut steps on the last steep slopes. The pioneers were thus not long in learning the art of Alpine-climbing, and it is interesting to note that Madame de Saussure, like visitors to Chamonix nowadays, followed the party's movements from the valley with a telescope.

De Saussure spent four and a half hours on the summit of Mont Blanc, making experiments on

the boiling point of water, and notes on the features of the landscape. He then descended, and camped a little below his station of the previous night. Thanks to the use of veils, he brought his party with whole skins and undiminished eyesight proudly the next day into Chamonix.

In his *Voyages dans les Alpes*, De Saussure records numerous observations made on the structure of the mountain and on the rocks gathered near the crest. He followed up this fine ascent by others in various parts of the chain, any one of which would assure us of his zeal and energy in research.

A number of younger men were fired by De Saussure's successes, and they ascended the higher valleys of their country into a new and entrancing world. It was popularly believed that demons threatened them with falling rocks; but these were worth fighting, after all. The clear blue skies and dazzling snowfields proved a sort of fairyland, and dangers were willingly faced, when each day's work brought something new to the explorer. Notable among these men were two engineers, Venetz and De Charpentier. They consulted the peasants who had spent their lives among the mountains, and they soon found out that these humble observers knew many things not yet realized in the old University of Geneva.

3. Glaciers and Moraines

When we see for the first time a range of mountains capped by snow in summer, we are probably some fifty or eighty miles away from it. Two landscapes seem to lie before us. One of them is clear, sharp, and defined, including blue-grey hills and deeply cut valleys, with here and there saw-like edges of bare rock, around which wisps of cloud gather, forming and melting away again as we gaze. But, if we raise our eyes, we suddenly become aware of a second landscape above the first one, pallid and white at noonday, flushing rose-red with the setting or the rising sun, the region where neither dew can lie nor rain fall, but where all moisture must come out of the air as crystalline stars in snowflakes, or as fairy needles in the frost.

At such a distance as we have chosen, this region of snow and ice seems divided from the lower world by a level line, the snowline. When we approach more nearly, this line appears more irregular, and long white pendants seem to hang below it against the mountain walls, and even to penetrate the dark masses of the pine-woods on the lower slopes. These narrow projections from the snowfields are the glaciers, the great ice-rivers, which bring down the chill breath of the summits to the fringes of the

Alpine fields (Fig. 29). We draw still closer to them; the air is hot and sunny round us, as we stand in the upland meadows, where the folk, in broad straw hats, are busy with their haymaking;

FIG. 29.—Glaciers descending from Snowfields on Mont Blanc, seen from the Brévent. (From Sir A. Geikie's *Text-Book of Geology.*)

but now the white upper world is only 4000 feet above us, and the foot of one of the rivers of ice lies only a few hundred yards away. We may well ask what it is that makes the region of snow,

gleaming up there in the sunlight, so different from that in which man ordinarily spends his life.

The great fact of importance is that the direct rays of the sun heat the air but little. They are absorbed, however, by the earth, which in turn gives out dark heat-rays to the air in contact with it. Water-vapour, moreover, accumulates in the layers near the earth, and not only becomes warmed by the heat-rays from the sun, but also prevents those returned from the earth from escaping into the higher atmosphere. Hence the air near the earth becomes warm, but the temperature steadily falls as we ascend. If we climb high enough, we shall reach a layer where it has sunk to 0° C., or the freezing point of water.

Warm air can associate with itself more water-vapour than cold air; that is to say, warm dry air passing across a pool or lake will allow invisible water-vapour to rise into it by evaporation; but, if colder conditions prevail, the amount of evaporation is lessened. Now warm air is lighter, bulk for bulk, than cold air; and air in which part of the ordinary gases, oxygen and nitrogen, is replaced by water-vapour, is lighter than dry air. Hence warm moist air may be distinctly lighter than the air at other places round it; a difference of atmospheric pressure is set up, and the colder air moves in, while the warm moist air is forced to higher levels, or, as

we say, it rises. But there is now less pressure above it, and it expands. As it does so, heat is used up, and it can no longer contain the same amount of invisible water-vapour; hence condensation of the water takes place, in proportion as the mass of air cools down. The moisture gathers in tiny globules round the far smaller floating specks in the atmosphere, and clouds are seen, growing along a particular level above our heads. These clouds are composed of an immense number of water-globules.

But the body of air may retain a certain amount of moisture until it has risen to the level where the temperature is as low as the freezing point of water. The height to which it will have to rise will of course depend upon the place and season; but any moisture condensed at or above that level will come out in the solid form, that is to say, as snow-particles and not as water-globules. Hence above our heads, even in summer, there is what may be called a snow-level in the atmosphere. A high mountain may pass through it, and any moisture deposited on the rocks above this level must be in the form of snow and hoar-frost. The snowline shows where the surface of the mountain cuts the snow-level.

This burden of snow upon the highlands is partly got rid of by dangerous slips and avalanches, but mainly through the compression of its lower layers

into granular ice. Tongues of this ice, as we have seen, are squeezed out in the form of glaciers down the valleys on the mountain-flanks, until they reach a level that is too warm for them. They are thus continually being fed by new snow above, and melt away into true rivers down below. After a succession of damp seasons, the amount of snow above may be so great that the nose of the glacier is pushed farther down into the lowland before it melts. After several dry seasons in succession, it may withdraw farther up the valley. When it withdraws, the rock-floor over which it has been slowly moving becomes revealed.

These were the ice-rivers that attracted Venetz and his associates. The problems set by glaciers before inquisitive mortals had yet to be worked out properly. The explorers saw how stones of all sizes fall off the mountain-sides on to the surface of the glaciers and are carried forward by them. Where the ice melts, these blocks are dropped on the lower ground. If the nose of the ice remains at the same point for a long time, the blocks build up massive walls, through which the streams from the melting ice have to make their way. These steep-sided barriers in the valleys were called *moraines* by the mountain-folk in Savoy (Fig. 30). Moreover, the water that runs out from the ice is white and milky with fine mud and sand, not clear

or peaty brown like the ordinary rivulets among our British hills. A great deal of material is coming out where the glacier melts away.

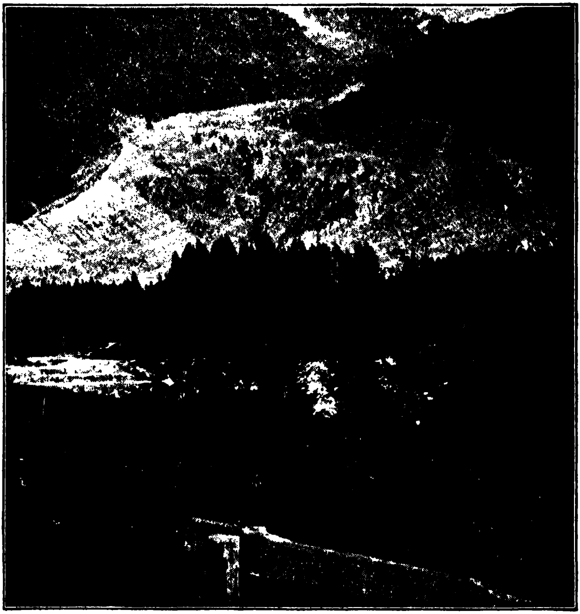

FIG. 30.—Glacier of Argentière, near Chamonix, Haute Savoie, showing wall-like lateral moraines, between which the glacier has now shrunk considerably. (G. Cole photo.)

4. Perraudin and the Lost Glaciers of the Alps

Playfair of Edinburgh, an eminent scientific observer, remarked in 1802 that the Swiss glaciers

might have once been much larger and longer than they are in our modern days. He saw that huge blocks, greater than those borne by streams, were left far away from their source where no ice now remains. Venetz and De Charpentier, who have been mentioned already as the followers of De Saussure, gradually came to the same conclusion. In his researches, De Charpentier carried the evidence still further, and found himself able to explain, not only the boulders, but also the scratched rocks that had puzzled Sir James Hall only a few years before.

Kuhn, a German, had noted scratched rocks in Switzerland in 1786. De Saussure must have known them also; but neither of these authors realized what the markings had to tell us about the past history of the Alpine valleys. It was left for a poor chamois-hunter in the Val de Bagne above Martigny to give us one of the soundest pieces of observation on which geologists now rely.

Jean Pierre Perraudin was a peasant who kept his eyes well open. The active chamois that he pursued gave him plenty to think about at most times; but he got to know the glaciers well, and the rocky walls that rose above them. At the foot of the ice he saw the solid rock smoothed and ground, and bearing numerous scratches, as if

it were polished rather imperfectly. In his walks down to his home from the "Jardin des Chamois" in the ice-world under the Otemma ridge, he traced these markings on the rock-walls all the way. M. Forel has recently published a statement left by Perraudin, which puts the matter very clearly.

Perraudin writes that he observed "marks or cicatrices made on solid rocks that were not decomposed (these marks are all in the direction of the valleys). . . . After a good deal of thought, I came to the conclusion, on going up to the glaciers, that they were caused by the pressure or weight of these masses, of which I find the marks at least as far as Champsec. This made me believe that the great mass of the glaciers formerly filled all the valley of Bagne."

De Charpentier, one evening in 1815, was making for the pass of the Great Saint Bernard, and was glad to spend the night in a hut on the hillside at Lourtier. By good fortune, this hut belonged to Perraudin. We may be sure that the two men talked long over the fire. Crags and glaciers were familiar subjects to them both, and De Charpentier had a stiff piece of work before him the next morning before he got over to the St. Bernard path.

Perraudin spoke of the great blocks of stone scattered all down the lower valley. He urged

that no floods could have carried them so far, and in this De Charpentier agreed with him.

"Well," said Perraudin, "a great glacier must have spread down the Bagne valley, away past Sembrancher and the bend at Le Brocard to Martigny."

De Charpentier shook his head at this. The Glacier d'Otemma, bearing the snowfield called the Jardin des Chamois on its back, was ten miles away up the Val de Bagne. A great curved moraine covered the main part of its nose, and it evidently had stood for a long time where it was. As for Martigny, this was fifteen miles farther below Lourtier. Perraudin's ancient glacier must have shrunk away for five-and-twenty miles. De Charpentier, who tells us of his talk in the hut, honestly says that the idea seemed "so extraordinary, even so extravagant, that I did not think it worth the trouble of serious consideration."

But in a few years he was thoroughly convinced of the truth of Perraudin's remarks, and became the first to bring the matter before the notice of scientific readers.

The Swiss Alps were not even then an easy place to move about in. A few lumbering carriages began to take travellers over into Italy, on roads opened for quite another purpose by Napoleon; but most of the valleys stretching up towards the

glaciers offered hardships to the ordinary traveller, such as now fall to the lot of mountain-climbers. There were no pleasant inns to return to after a long day's ramble; the chief men in a village made up for this by taking strangers into their houses, as they still do in Scandinavia, at a very moderate charge. The Swiss explorers between 1815 and 1840 worked hard to understand their native country, and thus laid a firm foundation for the study of the ice-world in other lands.

Perraudin had perceived how the scratches on the rocks, as well as the old moraine material, could be used as scientific evidence. We have all now come to see that there is a close connexion between the carrying of rock-masses and the striation of the valley-floor. Since a glacier does not mould itself perfectly to the valley down which it is being pushed, cracks arise in it, and a good many stones fall down these openings into the lower part of the ice. Sand and mud get washed in also, as the water from the surface of the melting glacier plunges in cascades into the unseen depths. The glacier itself, moreover, plucks off stones from its bed or from the bounding walls, if the cracks or joints in the rocks over which it passes are suitably arranged. Hence a good deal of stuff is carried along in the body of the ice, and this material becomes scratched as it

is dragged onward, in contact with the sharp sand held by the glacier. The sand and stones also scour the floor of the valley and its walls. If the glacier from any cause retreats, the rocks are seen to be polished and moulded by the rasping action, and to be beautifully marked with the scored lines and grooves that were observed by Sir James Hall in Scotland.

5. The Lost Glaciers of the British Isles

It is now time to see how the views of the Swiss geologists came to be applied to explain the mysterious scratched surfaces and the accumulations of boulder-clay and gravel in our own islands. In 1832, Louis Jean Rodolphe Agassiz, who was destined to become a distinguished naturalist, was made Professor of Natural History at the Academy of Neuchâtel. He was only twenty-five, but such confidence was felt in him that his salary was defrayed by a special subscription among the citizens. Agassiz came under De Charpentier's influence, and was soon convinced of the former extension of European glaciers. He took, indeed, an exaggerated view of the mantle of ice that, as he believed, once wrapped about the world; but his local studies in the Alpine valleys furnished him with evidence of great importance. He specially observed the rounded surfaces of rock, moulded and

scratched by glaciers in old days, and these became generally known by the name of *roches moutonnées*.

De Saussure had invented this quaint term at

Fig. 31.—Prof. Louis Agassiz, about 1865.

the end of the eighteenth century, but he did not recognize that his hummocky rocks had anything to do with ice-smoothing. In the second volume of his *Voyages dans les Alpes*, he wrote:

"Behind the village of Juviana or Envionne [the modern Evionnaz in the valley of the Rhone] we see rocks with the form that I call *moutonné*. . . . The mountains to which I apply this term are formed of a group of rounded bosses, sometimes covered with woods, but more often with grass, or at most with brushwood. These closely set and repeated hummocks unite to produce the effect of a good thick fleece, or of those wigs that are also styled *moutonné*." De Saussure goes on to say that the *moutonné* structure enables one to judge at a distance of the nature of the rock of which a mountain is composed; he noticed that the hummocks occurred in the hard old "primary" rocks and not on slate or limestone. It is, of course, true that what we now call *roches moutonnées* are best seen where the rock is of a resisting nature, and where it does not lend itself to "plucking" action under moving ice, or where it is not liable afterwards to solution, like limestone, in natural waters. But all rocks, as we now recognize, are capable of assuming the *moutonné* form when subjected to glacial action.

Dr. William Buckland, the famous Professor of Geology at Oxford, visited Agassiz at Neuchâtel in 1838, and compared the rounded rock-surfaces with those noted by him in the valley of the Tay in Scotland some twenty-seven years before.

Agassiz himself then came to Scotland, and read a paper on former British glaciers before the Geological Society of London in 1840. An excellent account of the discussion that took place on that memorable evening has recently been published in the *History of the Geological Society* (1907). Dr. Buckland had previously held that huge floods must have caused the features he had seen. He stated that he had "set out from Neuchâtel with the determination of confounding and ridiculing" Professor Agassiz; but Agassiz and Switzerland had now converted him. He frankly set aside all his own former views, and admitted that the scratched rocks and heaps of boulders in our islands were due to glacial action. In so doing, he was opposed by many of his friends; but he had marked out the path along which he felt that he must walk. Young Charles Lyell, whose *Principles of Geology* had already made such a profound impression, now found his old master in firm agreement with himself. Lyell, and his contemporary von Hoff in Germany (p. 56), had maintained that the proper way of reading the puzzles which the earth sets before us is to see what is actually going on at the present time upon its surface. These two writers insisted upon the study of causes now in action, before calling in unknown catastrophes as a way out of any difficulty.

Buckland always plunged into controversy with the cheerful air of a giant who is going to win; and in glacial matters he now joined his forces with those of Agassiz and Lyell. It is pleasant

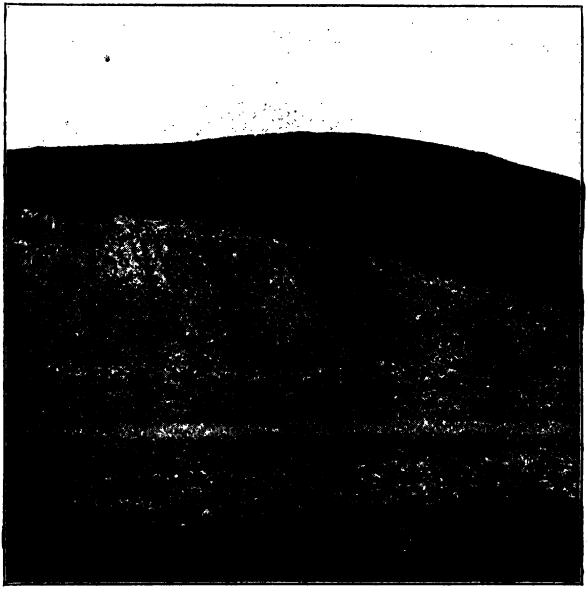

FIG. 32.—Arctic glacier, darkened with clay and boulders carried within it. Melting side-wall of the Nordenskiöld Glacier, Spitsbergen, in 1910. (G. Cole photo.)

to think that at the back of all these trained men of science was Perraudin the chamois-hunter, who had gazed on the face of Mother Earth as they did, and who had learnt from her one of the great secrets of the fairyland in which he dwelt.

We may now well believe that glaciers like those of Switzerland once existed in our islands, and so recently that their traces remain fresh upon the rocks. When we study the scratches further

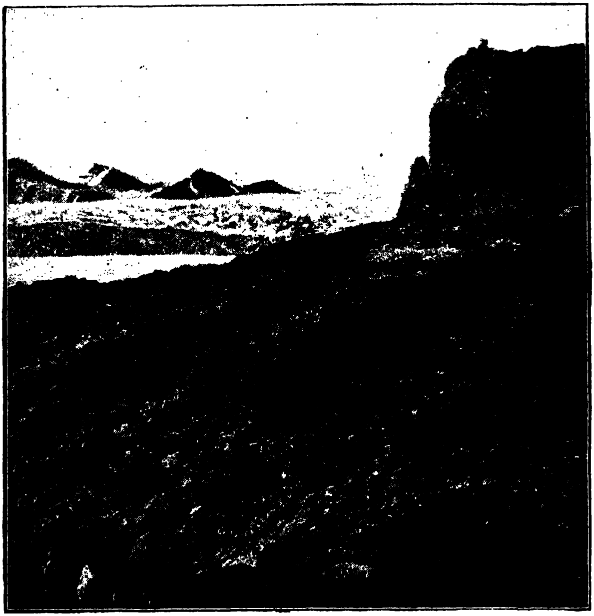

Fig. 33.—Von Post Glacier, Spitsbergen, in 1910, with boulder-clay deposited by it during a previous advance. (G. Cole photo.)

and especially the boulders carried across the country, we shall have to look beyond Switzerland for a full explanation of what we see. Northern Europe has not merely had her own local glaciers.

She has suffered from an enormous ice-invasion, the source of which lay in the north of Scandinavia. The story of this "Great Ice Age" is one of the strangest that we know, and the whole surface of Holland, Denmark, and northern Germany is cumbered with material laid down as the ice-sheets passed away. Broad ice-sheets in the Arctic lands gather so much broken rock within themselves that their lower portions become quite dark with mud and stones (Fig. 32). When they retreat, a true boulder-clay is left behind, as may be admirably seen at various points in Spitsbergen (Fig. 33). These great and almost level glaciers, coming down with fronts several miles broad into the sea, give us the best picture that we know of the ice that once lay across our isles.

CHAPTER VII

THE THROAT OF A VOLCANO

1. The Death of Caius Plinius Secundus

The general movements of the ground, as we have said in Chapter II., are very slow in comparison with human life. We may notice in some places that harbours become shallower by an uplift of their floors, while rocky islands slowly grow in

area; but we cannot hope to sit down and watch the rising of a mountain-chain. Now and then, however, we may be in a position to see something startling. The old earth seems truly alive beneath us, and then we feel very small upon its surface. Volcanic regions offer terrible displays, both of construction and destruction. All the slave-labour of ancient Egypt or of Rome never added such piles of material to the earth as an active volcano will heap up in twenty-four hours.

It is not always easy to observe volcanoes. The noise of the explosions frightened away people in the old times. Stones of very unpleasant sizes may be flying in the air, and falling through the roofs of cottages. Now and then streams of molten rock move slowly across the country, burning the grass and brushwood, wrapping round trees, pushing across walls, and even entering streets and court-yards. At other times, or perhaps even at the same time, choking dust may be thrown out. The air is full of it, the sun seems blotted from the sky, and the colour fades weirdly out of the landscape, as the fields become covered with a grey layer of powder, which thickens every hour. Life may be made impossible, and the inhabitants of the district have to withdraw until all is over. In violent cases, they may be killed in thousands and all observation is at an end.

Naples, however, has always been a convenient spot for the study of volcanoes. Vesuvius rises near to it, no higher than Ben Nevis above the sea. The prevalent westerly winds carry away the volcanic dust towards the Apennines, just as it threatens to become intolerable during a great eruption. The villages in that direction suffer, but Naples is usually spared. The flows of lava, the molten rocks that occasionally descend to the sea-shore, fail to reach the city. A volcanic area, with numerous dead craters, lies to the west, between Naples and Baja; but the only sign of activity in this region is now the sulphur-jet of Pozzuoli. (See map, p. 199.).

Vesuvius has thus become a model volcano, which thousands of travellers visit every year. An observatory has been built high up on its slope, where scientific work is carried on, even amid the turmoil of great eruptions. Lava may flow across the approaches to it, and cut it off from Naples; but the roadway is in time restored. The electric railway that carries tourists almost to the summit of the mountain may be torn by falling masses, as it was in 1906, and buried in heaps of white volcanic dust; but it is renewed as soon as possible, and the stream of visitors goes on. No one can now write or even think about volcanoes without having Vesuvius ready to his mind.

The Romans, however, and the Greek colonists of Campania before them, knew nothing about the structure of volcanoes. The beautiful hollow in which Spartacus and his gladiators had sheltered did not suggest anything terrible to them. In A.D. 63 the ground below Vesuvius was shaken by a serious earthquake. Pompeii, a prosperous and pleasure-loving city, was partially destroyed. But earthquakes are common in Mediterranean lands, and are not as a rule connected with volcanic outbreaks. They are probably due to the slipping of rock-masses on one another within our restless earth. Sometimes the cracks that arise allow hot matter to come out from below. More commonly volcanoes break out along weak lines in regions of unrest, and earthquakes occur also in these regions. But the great world-shaking earthquakes are often most intense where no volcanoes are now active.

So the dwellers in Campanian villas, all along that favourite shore, restored the damage done by the earthquake, and sent back their frightened slaves to the vineyards on the Vesuvian slopes. Sixteen years passed, and then at length the mountain showed its character. The eruption of A.D. 79 has been described again and again. Our best authority is Caius Plinius Caecilius Secundus, whom we know as the younger Pliny, and who

wrote two admirable letters on the subject to the historian Tacitus. What concerns us here, however, is the eagerness of his uncle, Caius Plinius Secundus, in research, when the great exploded dust-cloud rose suddenly from the summit of Vesuvius.

This studious worker was revising the thirty-seven books of his *Natural History*, for which he had made twenty thousand extracts in his note-books. He had published the first edition two years previously in Rome. He saw the strange cloud rising above Vesuvius from his house on the promontory near Baiae, where he was on duty as admiral of the fleet. His nephew was copying a manuscript for him, and preferred not to be disturbed; but the uncle thought the phenomenon "extraordinary and worthy of closer examination." The cloud by this time was "sometimes bright, and sometimes dark and spotted, according as," says young Pliny with considerable acuteness, "it was more or less impregnated with earth and cinders." His uncle ordered out a swift cruiser; but, just as he was leaving, a messenger came in. This man brought a letter from a lady living near the mountain, who asked to be taken off; it was clear that lives were now in danger across the bay. A new impulse was given to Pliny's spirit. His nephew stayed behind, and does not seem to regret it; but we must remember after all that young

Pliny's mother was in the house, and his presence gave her great support that evening when the volcanic showers fell on Baiae and Misenum.

The uncle now took several ships with him, to save such persons as he could. "He steered," says the letter, "direct to the point of danger," and found the sea rising and falling strangely on the shore, while hot masses of rock dropped upon his decks. The pilot advised turning back; but Pliny made the rowers pull to the south side of the bay, where he called on a friend, who had already packed up his goods, and was waiting for a favourable wind. The cloud from Vesuvius now glowed like flame across the dusk; but Pliny took his bath and supper, and cheered the people round about him. He then went to bed and snored peacefully, while stones and volcanic cinders fell into the court, and threatened to block him in his room. His host, far too anxious to go to sleep, at last had him wakened, for the walls of the house began to shake; and in the early morning, which was made dark as night by falling dust, the whole party emerged across the fields, their heads protected by pillows, and with torches in their hands. They reached the shore, but found the waves still running high. Pliny lay down to rest, and was suddenly suffocated, probably by volcanic vapours from the ground. His friends were scattered by

the sulphurous blast, and did not return until the darkness lifted three days later. They then found the body of this kindly man of science lying just as they had left him, "without any signs of violence, and looking more like a man asleep than dead."

The younger Pliny, in the manner of a skilful novelist, closed his first letter with a mere hint as to his own adventures; whereon Tacitus, in pure politeness, had to ask for more. Then followed the second letter, which showed that the nephew had also faced a severe ordeal at Misenum. The account of the fall of ashes in the darkness, and of the confused flight from Misenum, is like the work of a special correspondent, accurate, but anxious to impress his readers. Pliny's letter remains still terribly vivid after eighteen centuries. "At last the day returned; . . . every object seemed changed, being covered deep with ashes as if with snow.

Thus ended the first scientific enquiry into a great eruption. The excavations in the ash-buried city of Pompeii, which are steadily extending, continually bring the death of the Roman naturalist to our minds. Vesuvius has remained active ever since, and its most alarming outbreaks have been gathered into the last three centuries. Any year may witness a catastrophe that will put all its previous records in the shade.

2. The Growth of a Volcano

In 1538 an eruption occurred in the country west of Naples, which attracted the attention of many writers. The formation of Monte Nuovo provides us with an excellent object-lesson in mountain-growth. Sir William Hamilton, in 1773, translated the Italian accounts that were published a few months after the outbreak, and we may quote a few sentences from his version. One of the eye-witnesses, Marco Antonio delli Falconi, wrote that on the night of 29th September a great quantity of ashes and pumice-stones mixed with water were thrown up from a spot near Tripergola.

The ashes fell even in the streets of Naples. "After the stones and ashes with clouds of thick smoke had been sent up, by the impulse of the fire and windy exhalation (as you see in a great cauldron that boils), into the middle region of the air, overcome by their own natural weight, when from distance the strength they had received from impulse was spent, rejected likewise by the cold and unfriendly region, you saw them fall thick, and, by degrees, the condensed smoke clear away, raining ashes with water and stones of different sizes, according to the distance from the place: then, by degrees, with the same noise and smoke, it threw out stones and ashes again, and so on by fits.

This continued two days and nights, when the smoke and force of the fire began to abate. The fourth day, which was Thursday, at 22 o'clock, there was so great an eruption that, as I was in the Gulf of Puzzole, coming from Ischia, and not far from Misenum, I saw, in a short time, many columns of smoke shoot up, with the most terrible noise I ever heard, and, bending over the sea, came near our boat, which was four miles or more from the place of their birth; and the quantity of ashes, stones, and smoke seemed as if they would cover the whole earth and sea."

On the Friday and Saturday people ventured to the spot, and found that a new mountain had been built up near the shore, some three miles in circumference. This is still called Monte Nuovo, and rises 440 feet above the sea. "So that this place has changed its form and face in such a manner as not to be known again: a thing almost incredible, to those who have not seen it, that in so short a time so considerable a mountain could have been formed."

On the following Sunday, some twenty of the hardy visitors were killed by a sudden outburst of hot dust, or smoke, as it was naturally called. Since then, the hill has remained quiet. It is clear that thoughtful persons who viewed its formation held that it was simply a great heap, added to the earth's surface by explosions from within. A

"mouth in the form of a cup" lay at its summit. This is the characteristic crater—the word simply means a cup—which we know to be a feature of volcanic mountains.

In a second account, the author, Pietro Giacomo di Toledo, says that he found the mountain already constructed on the third day (which would be Wednesday), and that he "went up with many people to the top." He looked down into the mouth, where stones were still rising and falling back again; and he records the outbursts that occurred on subsequent days.

Sir William Hamilton, in quoting these pamphlets in a letter to the President of the Royal Society of London, points out the importance of Monte Nuovo, as showing how a volcanic mountain may be built from the base upwards, by forces which are clearly active at some depth down within the earth.

All the older writers speak of flames and smoke, and "subterranean fires," as connected with volcanic action, though we now know that few real flames appear, and that eruptions have nothing to do with ordinary combustion. The water which is so frequently mentioned proves to be the real source of the explosions, and the "smoke cloud" contains fragments of rock, torn to pieces as this water escaped from them in the form of steam. These fragments are the volcanic "cinders," and, by

striking against one another in myriads in the air, they produce the fine volcanic "ash," which is wafted hundreds of miles before the wind. Dio Cassius says that the Vesuvian ash of A.D. 79 fell in Africa, Syria, and Egypt. We have yet more striking instances in later times. The dust from Mount Pelée in 1902 discoloured a newly painted building near Newport in Rhode Island, some eighteen hundred miles away; and dust from Krakatoa, the Javan volcano which was blown up in 1883, went twice round the world on high air-currents before it entirely settled down.

The appearance of flames is naturally produced by the great outrush of molten rock. The friction of the volcanic fragments with the air also develops electricity, and flashes of lightning break the darkness of the dust-cloud. The steam that has carried the fragments into the cold upper air, and is in some cases still escaping from them, condenses as rain, and falls in torrents, mingled with the dust. Mud-flows stream down the mountain slopes, and are quite as dangerous as the flows of molten rock.

It requires at all times some courage to study a volcano in full action. Various enquirers in the eighteenth century were attracted by the frequent outbursts of Vesuvius and Etna, the familiar volcanoes of the "Two Sicilies." Vesuvius had taken a long rest of five centuries, from 1139

to 1631. At the latter date wild boars found a home, among trees and brushwood, in the crater. However, on 16th December 1631, a great ash-cloud and seven lava-streams issued from the mountain. The coast-towns east of Naples were invaded and set on fire by molten rock, and 18,000 people lost their lives. Since then, eruptions became frequent down to 1751, when the Abate Giuseppe Maria Mecatti undertook a close description of what was going on. He continued his studies for several years. In the second book published by him, there is an effective plate of himself and his companions boldly sketching the growth of a "montagnuola," a "little mountain," inside the crater of Vesuvius. Hot stones are being thrown out, and a peasant, Agostino Formisano, who climbed part way up the new cone, is shown as flying back in terror.

The continued examination of this cone by Mecatti no doubt inspired Sir William Hamilton a few years later. Meanwhile, Giovanni Maria della Torre published a history of Vesuvius, with a view of the interior of the crater when it was active in 1755. Scientific curiosity was well aroused.

Sir William Hamilton, British Ambassador at the court of Naples in the eighteenth century, took a cultivated interest in many things. He collected antique vases, ornaments, and polished stones. But

he had the observing instinct of a good naturalist, and, from the day of his arrival in Naples in 1764, he made a personal study of Vesuvius. In this way he was able to prove systematically how a volcano grows.

He frequently ascended the mountain, which then, as now, consisted of two parts, the great ring of Monte Somma, broken away upon the seaward side, and the steep cone of Monte Vesuvio, cradled, as it were, in the curve of Somma. He spent more than one night upon the cone, and describes "a most beautiful and uncommon cascade," formed by a flow of molten lava, which he examined as nearly as he could. He does not seem to have recognized the "thick white smoke" rising from it day and night as steam.

Vesuvius was unusually active in 1766, but calmed down in December. The cone then had a shallow crater in its top, floored by a plain of lava, only 20 feet below the edge on which the observer stood. A "little mountain" rose from this plain, just as Mecatti had seen twelve years earlier, over the principal chimney of the volcano. It was possible to ascend this also on quiet days, and drop stones down into its throat.

In March 1767, cinders, ashes, and pumice-stones were thrown out on to the "little mountain," so that its top in time became visible above the crater-

rim. Lava even flowed down it, and rose over the edge of the older crater. By 15th October the little cone was about eight months old and 19·7 feet high.

Hamilton watched its increase most minutely, making drawings of it from time to time. "I make no doubt," he writes, "but that the whole of Mount Vesuvius has been formed in the same manner." Some of those who came after him in the study of volcanoes believed that the mountain from which lava flowed had been raised by a bladder-like upheaval of the ground. Some support, as Lyell shows, was actually given to this view by two of the early accounts of the formation of Monte Nuovo. Hamilton, however, saw how, little by little, even the greatest volcanoes might be piled up. "Upon the whole," he says wisely, "if I was to establish a system, it would be, that *Mountains are produced by Volcanoes, and not Volcanoes by Mountains.*" He insisted upon the layer-structure of such mountains; they are formed of beds of ash or lava, one above another. Such layers can be seen in the walls of their craters, where repeated explosions have blown away some of the material, and have formed clean sections through the mass. The crater of Monte Nuovo is said to reach down almost to sea-level, and it furnished a conclusive view of the structure of the hill.

Sir William Hamilton's "little mountain" eventually grew big, as his drawings clearly show, until it covered all the older crater and joined up its slope with that of the original cone. Between May and November 1767, Vesuvius had grown taller by some 200 feet (Fig. 34).

In October, however, during this increase, a very notable eruption had occurred. On the 19th, Hamilton hastened from his villa at eight in the morning, accompanied by one peasant, and took his stand in the valley between the wall of Somma and the cone, where lava was descending rapidly, giving off its characteristic "white smoke." About noon, only a quarter of a mile away, as he tells us, "the mountain split." A fountain of lava shot up and rolled down on the observers like a torrent. With much cause, they "ran near three miles without stopping," while pumice-stones fell on them like hail. Soon after safety was reached, another lava-flow broke out, so that both sides of the mountain were deluged, as Hamilton shows clearly in two quaint old drawings. His villa near the coast had to be abandoned, and the explosions that night blew open doors and windows in the city of Naples. Hamilton suggests that regions of the mountain soaked with rain may have contributed to the hissing noises that were heard. This idea has been revived by another writer, Dr. Johnston-Lavis, in

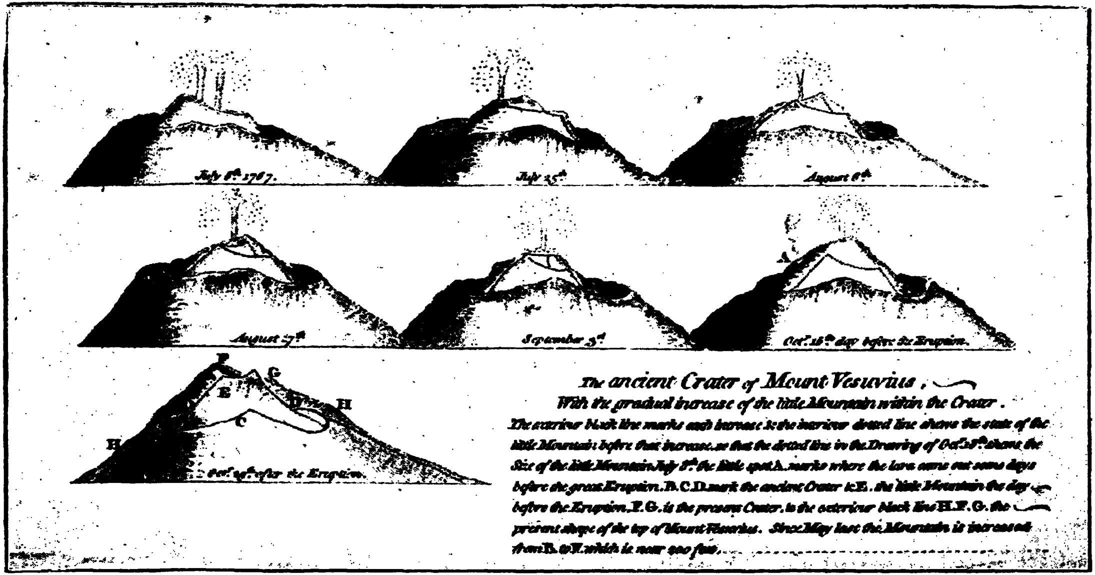

FIG. 34.—Hamilton's Drawings of the Growth of a Cone on Mount Vesuvius in 1767. (From his *Observations on Volcanoes.*)

our own time, to account for some of the water that escapes from lava-flows.

Hamilton extended his observations to other Italian regions, and became convinced that many old volcanic areas exist, where the subterranean forces have died out. We have quoted so much of his careful work, to show how, without thought of personal toil and risk, he discovered in what manner volcanic mountains grow. This wealthy man of the world, who in London might have been a cultivated idler, now stood far ahead of the scientific opinion of his time.

3. Volcanic Energy of To-day

Probably no other large volcanic cone has so clear a history as that of Izalco in Salvador. This mountain rises some 3000 feet above the plain, thirty miles west of the city of San Salvador, and its top is 5000 feet above the sea. Yet it is not 150 years old. In the winter of 1769, earthquake shocks had been common in the district. On 23rd February 1770, the earth opened, and, like the New Mountain of Pozzuoli, a hill became built up. The estimates of various travellers differ a good deal as to its height from time to time; but the American Stephens met a priest at Sonsonate in 1840 who had seen practically the whole of the mountain's growth. Izalco is still erupting and

still growing, and is only one example of the earth's activity in a region where earthquake shocks and violent eruptions are unfortunately very common.

After this, we can readily believe, with Hamilton, that volcanoes are associated with mountains because the mountain cannot help growing where the material is thrown out. Islands may be built up in this way from the bottom of the sea. The Sandwich Islands, and numerous others in the Pacific Ocean, are thus merely the tops of huge cones that have held their own against the waves and have grown upwards as dry land. Sheet after sheet, to this day, the fluid lavas of Hawaii or Samoa are raising the surface of the country. We shall see in the next chapter how Hamilton was undoubtedly right in saying that many volcanoes had existed in ancient times, which are now to be recognized only by the structure of their rocks. There is nothing, however, in their characters that would lead us to believe that, at any period since living things appeared upon the earth, volcanic action was more general or more violent than it is now. The lines of earth-movement have shifted, and volcanoes have died out in one region and broken out in another. But at the present day they remain as the most impressive evidences of the forces that are active down below.

In recent times, moreover, we have had some of the most tremendous volcanic manifestations known to human history. The destruction of the peak of Krakatoa off Java in 1883, with its accompanying sea-waves and air-waves, has been described by many modern writers. For a long time blocks of pumice, the products of the explosion, cumbered the Indian Ocean as far as the east coast of Africa. The still more recent eruptions in the West Indies, however, deserve special mention, since those who studied them, in times of exceptional stress and danger, brought back entirely new knowledge in regard to the outpouring of volcanic dust.

4. The Death-Blasts of St. Vincent and Martinique

The islands of St. Vincent and Martinique were known to be of volcanic origin. They form part of a chain that no doubt overlies one of the lines of weakness in the Central American region. They suffer from numerous small earthquakes, and hence those that prevailed in 1901 attracted no special attention among the inhabitants. The mountain known as the Soufrière rises to a height of 4000 feet at the north end of the island of St. Vincent. Its main crater is nearly a mile across at the top, and water had formed a green lake in its bottom. Sulphurous vapours were freely given off from this

lake, but the waters were not warm, and bushes grew on the steep crater-sides.

This volcano had been active in 1812, when lava is said to have descended as a "tide of liquefied fire" into the sea. Drs. Anderson and Flett believe that we have here an example of the singular flows of hot volcanic dust, which were so terrible a feature of the outbursts of 1902. On 6th May 1902, the Soufrière was again in eruption, though women engaged in the fish-trade crossed the mountain by their accustomed path that very morning, and looked down into the crater. The same women, returning westward the next day, came upon a scene of great disturbance. The lake had been partly blown out, and the whole crater was in a turmoil. They could not pass into the devastated land on the farther slope; but it soon became known that a serious eruption was in progress. After the lake was emptied, a torrent of hot ash rolled down at 2 P.M. on 7th May on Chateaubelair Bay, destroying in its path every living thing in the open fields.

Those who happened to be in boats along the coast saw this "black cloud" descending; but its swiftness gave them no hope of escaping from it. The survivors state how they even dived into the sea, coming up more than once to find the air full of dust, which parched and burnt their throats.

On 18th May there was another great ejection of ash, and heavy rains then washed down the fine dust in the form of destructive mud-flows over the north end of the island. Drs. Anderson and Flett arrived, on behalf of the Royal Society of London, early in June, and the present account is based upon their report. Meanwhile, the French island of Martinique to the north had attracted attention still more keenly.

Mount Pelée of Martinique, the Montagne Pelée, experienced an eruption of some violence in 1851. On 25th April 1902, it began again to eject rock-fragments; and two days later six residents from the city of St. Pierre climbed to its crater. To their surprise, they found a new cone built up within it, ten metres high and fifteen metres in diameter across its crest. This, however, was the last observation made on the mountain by inhabitants of St. Pierre. Their report was published in the local journal, *Les Colonies,* on 7th May. The editor concluded with the notice, "Our offices being closed to-morrow, our next number will not appear until Friday."

On the day when this notice was published, bombs were already crashing from Pelée's crest. At 2 P.M., away in the south, the Soufrière of St. Vincent exploded, after a rest of ninety years. The next day, Thursday, was the feast of the Ascension.

At 7.50 in the morning a volcanic avalanche, a burst of incandescent dust, swept down on the city of St. Pierre, and in two minutes 27,000 persons perished. The city broke into flame from one end to the other. The ships in the harbour were set on fire, and Captain Freeman of the *Roddam*, his seamen falling round him, alone steered his vessel into safety, as the cloud spread out and settled down.

Stories of poisonous gases, blasts of flame, and so forth, naturally prevailed for a few days. But the country was seen to be covered with grey volcanic ash, which lay in the ruins of the city. Father Parel, the Vicar-General, entered the bay with a rescue-party a few hours after the catastrophe. There was no living thing to rescue. The sun came out, pale and wan. "In the background," he writes "the mountain and its slopes, once so green, stand forth like an Alpine landscape. They look as if they were covered with a heavy cloak of snow." The destruction had been due to a special type of dust-cloud, travelling with immense velocity. Prof. Russell has well compared it to "the discharge of a great cannon" (Fig. 35).

Russell justly urged that steam, rather than any poisonous gas, was the cause of the death of so many thousands; and Drs. Anderson and Flett have since given us one of the most complete descriptions of the behaviour of these volcanic blasts.

These two observers, after working in St. Vincent, were sailing in a ten-ton vessel on the

FIG. 35.—Eruption of Volcanic Dust from Mount Pelée in June 1902. (From stereograph, copyright 1902, by Underwood & Underwood, New York.)

evening of 9th July off St. Pierre. From the fissure on Pelée, puffs of steam were frequently rising; but now, in the twilight, a globular darker

cloud appeared, the behaviour of which at once drew their attention. Of this they write as follows:—

"It did not rise in the air, but rested there, poised on the lip of the fissure, for quite a while as it seemed, and retained its shape so long that we could not suppose it to be a mere steam cloud. Evidently it had been emitted with sufficient violence to raise it over the lip of the crater, but it was too heavy to soar up in the air like a mass of vapour, and it lay rolling and spouting on the slopes of the hill. The wind had no power over it, fresh protuberances spurted out from its surface, but it did not drift to leeward any more than if it had been a gigantic boulder. For a little time we stood watching it, and slowly we realized that the cloud was not at rest, but was rolling straight down the hill, gradually increasing in size as it came nearer and nearer. . . . It was a 'black cloud,' a dust cloud, and was making directly for us."

The observers prepared to fly as soon as possible; the meaning of these "black clouds" had been too fully realized both in St. Vincent and in Martinique. "By the time the mainsail was hoisted we had time to look back, but now there was a startling change. The cloud had cleared the slopes of the hill. It was immensely larger, but still rounded, globular, with boiling, pillowy surface, pitch-black,

and through it little streaks of lightning scintillated."

This cloud spread out and spent its violence. "It lay almost like a dead mass on the surface of the sea." Half an hour later, red-hot stones were thrown out for a mile around the crater, and then suddenly, with what was like an angry growl, "a red-hot avalanche rose from the cleft in the hillside, and poured over the mountain slopes right down to the sea. It was dull red, and in it were brighter streaks, which we thought were large stones, as they seemed to give off tails of yellow sparks. . . . The main mass of the avalanche was a darker red, and its surface was billowy like a cascade in a mountain brook. Its velocity was tremendous."

The similar dust-cloud that destroyed St. Pierre is known to have travelled at a hundred miles an hour, covering eight kilometres in three minutes. Drs. Anderson and Flett sat in their boat, with its idly flapping sails, full in the line of the discharge.

"The display of lightning in the cloud was marvellous. . . . Many of the flashes were horizontal, others shot obliquely from one lobe to another, while along the base, where the black cloud rested on the steel-grey sea, there was a line of sparkling lights, constantly changing, varying in amount but

never disappearing. . . . We sat and gazed, mute with astonishment and wonder, overwhelmed by the magnificence of the spectacle, which we had heard so much about, and had never hoped to see."

There is the fine spirit of the philosopher in this last sentence; for it seemed likely that the observations would never come to be recorded. However, after despair had settled on the boatmen, who were rowing for their lives, a light puff of wind enabled them to sail again, and gave them heart. The cloud now seemed less violent; but it crept across the sea and on over the mast-head, still travelling at twenty miles an hour. A hail of pebbles fell on the deck. "We picked up the first that fell. It was about the size of a chestnut, and was cold to the touch, so we knew that we were safe."

As a result, we have the fine report on St. Vincent, from which we have quoted this description. The calm examination of a volcanic cloud of the kind that had devastated Martinique and St. Vincent led the authors to remarkable conclusions, which have since been widely supported. They believe that the cloud consists of lava-particles giving off imprisoned gases, the chief of these being steam and the second in importance sulphur dioxide, a compound of sulphur and oxygen common in volcanoes. The exploded mass poises on the crater-

edge and falls over, moving by gravitation down the outer slope. Mr. E. O. Hovey has shown how its particles scrape and score the rocks over which they rush.

The abundance of escaping gas enables the cloud to flow onward, where mere dry dust might have fallen and accumulated. This body of glowing rock-dust and hot escaping gases forms a veritable blast of death, displacing the ordinary air. Most of those whom it enveloped fell dead upon the instant. Their clothes were not charred, but their throats were scorched, and any place where the skin was exposed was marked by scars from burning. Death was so swift that in St. Vincent eighty-seven bodies were found heaped on one another in one shop, where the people had taken shelter from the rain of ash. The victims from whom the air was thus suddenly withdrawn were fortunate as compared with others. Some lived for one or two minutes, some for many hours. While 1500 persons perished in St. Vincent, at least 30,000 perished in Martinique. In St. Vincent a boy of fourteen buried his father and mother and seven brothers and sisters in one trench with his own hands.

In the midst of these horrors, scientific observers from America, France, or England, travelled through the islands, exposing their own lives for the hope

of what they still might learn. Prof. Heilprin in Martinique underwent volcanic bombardments as vigorous as those of any battlefield. He made ascents to the edge of Pelée's crater on two consecutive days, three weeks after the great outburst, but could see little through the volcanic storms. He returned, however, in August, after the adventures of Anderson and Flett. On 30th August, he climbed the mountain with Mr. Cochrane, three attendants, and seven other residents, who came as volunteers. A violent eruption was in progress, and the continuous roar of the volcano was appalling. Blocks of lava, so aptly called volcanic bombs, were flying freely through the air.

"For a half-hour or so," writes Heilprin, "we took refuge in a hollow sufficiently deep to about clear our heads, and waited. . . . Every scattering mass brought us to our feet, only to see and hear the fragments plunging into the abyss that lay to one side. Cochrane and I moved a piece higher up, and then abandoned the effort. 'Where did this last block burst?' I asked of my associate, and before my question was answered we were spattered with mud from head to foot by a great boulder, hardly smaller than a flour-barrel, which fell within ten feet of us, or less." The observers lunched under these conditions, and then retreated.

That evening the discharge of the volcano was

accompanied by one of the amazing electrical displays that marked the cloud-bursts of Martinique. Flashing through the darkness were "long-armed stars, and circles with star-arms hanging off from the border like so many tails." The explosions of this eruption were heard in the island of St. Kitts, two hundred miles away in the north-west, and in Trinidad, three hundred miles to southward. In the morning it was found that the villages of Morne Rouge, Morne Balai, Ajoupa Bouillon, and many others had been swept by a hot avalanche of volcanic sand. Heilprin was out helping the maimed and scorched survivors; but 2000 persons had perished, including Père Mary, the faithful priest of Morne Rouge, who had worked so nobly among his people after the wreck of St. Pierre.

5. A Great Explosion in Guatemala

Central America is accustomed to earthquakes, and the shapes of many of its conspicuous mountains are clearly those of volcanic cones. Guatemala was severely shaken on 18th January 1902. A sea-wave, due to earth-movement, rolled in on the Salvador coast on 26th February, sweeping away some two hundred people. On 18th April, Guatemala received a still more severe shock, which was felt as far north as the city of Mexico. On 10th May, two days after the destruction of St.

Pierre, Izalco in Salvador became active, after a rest of fifteen months. In August, the volcano of Masaya in Nicaragua, which had not erupted for forty-three years, responded mildly to the general unrest. A third great earthquake shook Guatemala on 23rd September.

The huge steep-sided cone of Santa Maria in Guatemala was generally regarded as extinct. On 24th October, however, stones and ashes rose from a new crater opened in its southern flank; and in a few hours the outburst surpassed in extent and intensity anything that had happened at St. Vincent or Martinique. Fortunately, the region, occupied by coffee-plantations, was thinly peopled; but some 2500 persons lost their lives.

Dr. Karl Sapper, now Professor of Geography at Strassburg, arrived that very day in Guatemala, and recorded the features of the eruption. It is not the fortune of every one to be received so startlingly in a foreign state. It was impossible at first to study the details of the outburst, or even to know what was going on, since an immense quantity of dust obscured the whole landscape, and hung thickly in the air for many days. Great rushing sounds were heard from Santa Maria, like a tremendous roar of escaping steam. The height of the eruptive storm was reached at 11 A.M. on the 25th. Stones as large as peas fell nearly ten miles

away to the north-east, and a big one went through a veranda, and into a room beyond, in a house more than three and a half miles from the mountain. Captain Saunders, on a mail-steamer in the Pacific, measured the height of the column of exploded dust. It rose seventeen miles or more into the air.

Electric flashes accompanied this great eruption, and flared across the darkness of the ash-cloud. The earth and air responded to the fierce excitement, and electric discharges took place not only from houses, but from the clothes and bodies of spectators. After the first days of November, the air cleared somewhat, and a new crater could be seen upon the slope of Santa Maria, sending up clouds of steam. On 24th November, three residents approached it, and found it to be an elliptical hollow, about three-quarters of a mile long and a third of a mile wide. Five active openings were discharging steam from the crater-floor.

The thick deposits of ash became compacted by their own weight, and streams cut their way deeply into them, giving sections like those familiar to us in the far older volcanic beds of Campania. Heavy rains washed much of the material down on to the lower country. The huge piles of ash and stones formed, however, serious obstacles to travelling when Dr. Tempest Anderson explored

the scene of destruction four years later. To him and to Prof. Sapper we owe our knowledge of this outbreak of Santa Maria, one of the greatest that has been recorded on the surface of the globe. Scientific men will never be wanting where so much is to be learnt concerning the activity of the earth, and they will seek truth even in the throat of a volcano. James Hutton understood this well when he wrote in 1785, "a volcano is not made on purpose to frighten superstitious people into fits of piety and devotion." The exploits of Mecatti and Hamilton were no doubt present in his mind.

CHAPTER VIII

THE STORY OF THE GIANT'S CAUSEWAY

1. A Visit to the Causeway

After a brisk drive from Portrush, or a run in the electric tramcar, we walk down from the brow of the hill to the gateway of the Giant's Causeway. On our way we have seen the chalk, forming the White Rocks along which the road has been cut; and above this white limestone lies black basalt, weathering to a warm brown, and increasing in importance as we near the great promontory of

Bengore. Even when we are some miles off, we can see bedded structure in the basalt; one layer rises above another on the face of the fine dark cliffs, and some of these layers are broken across by cracks, which divide the mass into regular columns, and make it resemble a gigantic palisade.

Fig. 36.—Columns at the Giant's Causeway, Co. Antrim. (R. Welch photo.)

The Giant's Causeway itself is apt to be disappointing. It looks small enough against the noble background of the cliffs. But its very regular jointing renders it justly famous, and we walk over its surface with increasing admiration. It is formed by a projecting mass of basalt, washed by the sea at its northern end, and its surface is

divided by cracks into almost regular hexagons. These hexagons are the ends of columns, which show fine straight surfaces on the sides of the Causeway. The columns are broken across by cracks, which in some cases curve downwards and in others upwards, so that the end of a column may show a surface like a basin, in which water gathers, or, on the other hand, like a basin turned upside down, off which the sea-spray runs.

At first we think of the regular bodies known as crystals. Surely these wonderful blocks, a foot or more in diameter, may be evidences of crystalline forces acting on a gigantic scale. There are crystals of quartz in some of our museums as big as the carved columns of a building. Crystals of apatite (phosphate and fluoride of lime) found in Ontario in Canada are nearly as striking; and both these examples are six-sided, like the columns of the Giant's Causeway. The Rev. Wm. Hamilton and other older observers thought that the Causeway columns had something to do with crystallisation.

Crystals, however, are marked by the wonderful constancy of their angles. If our columns are crystals, and their cross-sections are regular hexagons, their angles must each measure 120°. Though Nature seems to have worked towards some such end in this case, she has rarely succeeded, and serious deviations from 120° will soon be

found, if we sit down and study carefully. Besides this, there are four-sided, five-sided, and even eight- and nine-sided columns in the Causeway area, and no crystalline law can be found out from them by measuring.

The columns, in fact, even when they are six-sided, are quite as defective as the works of some primitive mason. Are we, then, to believe that veritable giants built this causeway running out to sea, and also the monumental colonnades upon the cliffs behind it, where the same structures appear on a still more handsome scale?

Such was the natural belief of our ancestors long ago; and the early Scots, an Irish race that gave its name to Scotland, as they sailed between this coast and the holy island of Iona, must have soon become acquainted with the rock of Staffa, rising from the western surge. Here similar columns appear on the walls of sea-carved caves, while a roof of tougher basalt forms the upper plateau of the islet. Men at once connected Staffa in their minds with the Giant's Causeway, and urged that the causeway ran on under the sea, to reappear at Fingal's Cave and form a passage-way for kings and heroes.

To this day dwellers in Antrim will tell you of this connexion between their coast and Scotland, and the idea shows at least a sort of geological

observation. The rocks as well as the structures at the two places are similar. Whatever explains Staffa explains the Giant's Causeway.

What, then, is basalt, this dark rock, sometimes massive, sometimes cracked into columnar forms? Can we tell its age by fossils? Was it laid down on land or in the sea? When we examine it closely, it presents characters quite different from those of the sandstones, or clays, or limestones, that form our common stratified rocks. It is made up of glancing little crystals, some white, some greenish, some black, and often so small as to be distinguished only with a pocket-lens. Sometimes a sort of groundwork, like dull black glass, can be made out in addition. Now and then the rock seems as if it had been blown up into bubbles; and the hollows of these bubbles are lined in many cases with beautiful white crystals, which seem to have been deposited in them after the bubbles had been formed.

The rock is heavy, distinctly heavier than granite or limestone, and, if we powder it, black ores of iron can be pulled out easily by a magnet. There is thus a good deal of iron in the rock, and this accounts for the brown rust that colours the surface of the Giant's Causeway, and gives such a rich tone to the soils on the basalt fields round Bushmills. Search as we may, we shall find no

trace of fossils in the rock-mass of the Giant's Causeway. Higher up in the cliffs, a seam or two of coaly matter appears between the layers of basalt, showing that trees grew while the rock-mass was being deposited. A handsome broad red band runs round the headlands about half-way up the cliffs. When we examine this carefully, we find that it is due to the alteration of the basalt, which has rotted away and rusted to a strong red colour along this particular zone.

The remarkable regularity of the Causeway columns was known to many observers in the seventeenth century. Letters were written about them to the Royal Society of London in the reign of William III., and Dr. Thomas Molyneux of Dublin, in conjunction with the Dublin Society, sent an artist to make a complete drawing of the scene in 1696. This quaint picture gave a very fair idea of the way in which the Causeway projected seaward from the cliffs, and it also showed columns at a number of points in the hillsides. Dr. Molyneux himself could not travel so far from Dublin; but he gave a careful description of the material of the Causeway, which he said was the same as Pliny's *Lapis Basaltes*, the rock now known as basalt. This rock was at that time still confused with black flint or "touchstone," a hard stone used for testing gold, since the metal leaves a characteristic

streak when rubbed upon its surface. But the origin of these and many other rocks was still unknown to the naturalists of the seventeenth century.

As we have seen, and shall see again and again in these chapters, the geological history of our own country cannot be entirely learnt at home. Each part of the earth has gone through many changes, and we must often go far afield before we find something happening here or there, which will explain what happened long ago in the British Isles. The Giant's Causeway received its true appreciation from a Frenchman in 1763, and from a man who had already compared the rocks of various lands.

2. The Volcanic Lands of Central France

France possesses a singular variety of scenery, from the flat lands of Picardy, traversed by canals, to the limestone ridges of the Jura, and to the superb snow-covered heights of the Pelvoux and Mont Blanc. In the centre of the country lies the upland of Auvergne, divided among the departments of the Puy-de-Dôme, Cantal, and Haute Loire. Here are the rocks, some of them quite fresh and modern, others deeply cut into by the weather, which enabled geologists to read the story of the Giant's Causeway.

The heart of Auvergne is a high bleak country, mainly devoted to pastures and cheese-making. The population is sparse, and the villages are poor and small, connected by winding and unimportant roads. Down the east side of it runs the highway to the hill-towns of Languedoc and to the Roman cities that gathered on the delta of the Rhone. The great road from "Paris to Toulouse and Spain," as the signposts style it, runs well to the west of Auvergne, climbing into poor lands between Limoges and Cahors, but avoiding the true central plateau of the country. Towns thus lie round about the plateau, in the more fertile lowlands, and Clermont-Ferrand on the east has always formed a starting-point for travellers who wish to explore the high-land.

We rise quickly over granite slopes as we go westward from Clermont, and we find ourselves, at the end of our climb, among a very singular group of hills. The chief of these is the well-known Puy-de-Dôme, a steep pudding-like mass of compact grey rock; but its neighbours are mostly formed of loose cindery materials, black or grey or red. They are conical, with apparently flat tops; but, when we look down on them from the central Puy-de-Dôme, each is seen to have a cup-like depression in its summit. Often the cone has been broken down on one side; and here and there a

mass of rugged rock has spread out from one of these hills, like a long serpent running across the plateau. These bands of rock even descend into some of the valleys which stretch down towards the lowlands. They are usually overgrown with heather, rough scrub, or trees, in contrast with the grass-covered or cultivated lands on either side.

In the middle of the eighteenth century, there dwelt at Clermont-Ferrand a chemist named Ozy, who has left us a valuable letter dealing with the scientific exploration of the plateau. He tells how in 1750 he was visited by Olzendorff, an Englishman, and Bowls, an Irishman, who were examining lead-mines in Auvergne. Lead ores are still worked across the plateau at Pontgibaud. Ozy guided the strangers to the summit of the Puy-de-Dôme, and he says that he there first learnt to recognize volcanoes and lava-flows among the hills that were so familiar to him. "Bowls," who was certainly William Bowles, the Irish mineralogist, seems thus to have been the first man to point out the true meaning of the conical mountains of central France. The cup-like depressions were seen to be volcanic craters, and the streams of rock from them were explained as lava-flows.

The next year, in 1751, J. E. Guettard, an apothecary's son who had become a naturalist, went down to Auvergne with a scientific friend,

Malesherbes. Guettard had seen stones brought from modern volcanoes. As he journeyed southward from Paris, he was struck by the resemblances between these stones and the dark grey rocks of

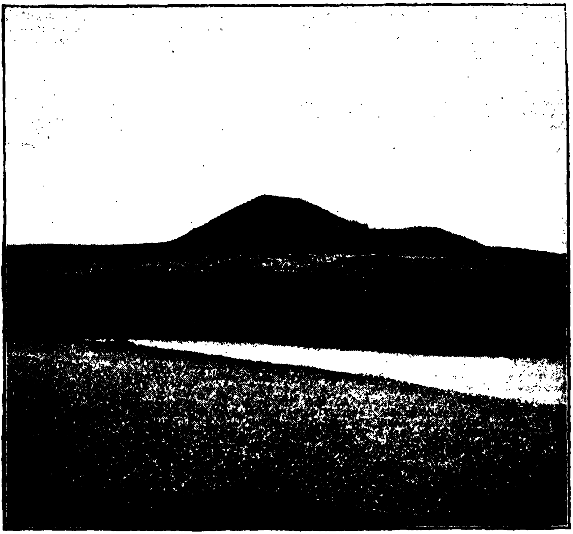

FIG. 37.—The Puy de Montgy, a volcanic cone west of Royat, Puy-de-Dôme, France. (G. Cole photo.)

central France. The two friends called on Ozy when they arrived at Clermont, for this apothecary seems to have been recognized as the proper guide for men of science. The three then climbed the Puy-de-Dôme, the ascent of which is still the great excursion for every visitor to Clermont. From its

summit Guettard at once recognized cones and craters and dark rugged lava-flows, such as he knew occurred in volcanic lands. In 1752 he published his conclusions before the Academy of Sciences in Paris, and thus made known the true nature of the mountains that had been piled upon the plateau of Auvergne. About the same time, La Condamine, another French worker in science, was travelling in Italy, and traced numerous extinct volcanoes and old lava-flows in the neighbourhood of Rome, from their resemblance to what he had seen in the active region of Vesuvius.

Guettard noticed that some of the dark rocks of Auvergne were in reality basalt, and that these had sometimes become split into regular columns, like those of the Giant's Causeway. But he tried to separate these from the masses that he recognized as lava-flows, and would not admit that basalt could ever have come in a molten state from the interior of the earth. It is true that many of the basalts of Auvergne, and of the Vivarais to east of it, have become so cut into by the weathering action of rain and rivers that they look like mere isolated sheets of rock on the surface of the country. The volcanic centre or crack from which they flowed can no longer be discovered; they represent only the dissected relics of old volcanic masses. The great plateau of Gergovia, which was success-

fully defended by Vercingetorix against Julius Caesar, is formed by basalt cut away from its connexions on every side. Yet it is strange that so good an observer as Guettard continued to separate such basalts from his volcanic rocks.

Twelve years later, however, in 1763, another observer came into the field. Nicholas Desmarest began life as a poor boy, and owed his education to the kindness of a religious order at Troyes, in the midst of the great open country of Champagne. His masters noticed his keen intelligence, and sent him to Paris, where he became a private tutor. Here he came into contact with scientific men, and soon found a place in a group of observers that included Buffon, the Duc de la Rochefoucault, and D'Alembert.

D'Alembert himself had been forced, as we often say, to live by his wits, or, to put it much better, by his powers of study and application. He had already become distinguished as a mathematician and a physicist. He worked with Diderot in Paris on the famous *Encyclopædia*, one of the greatest undertakings of the time, and refused tempting offers to attach himself to foreign courts. This type of man was a good friend for young Desmarest, who was steadily feeling his own way in Paris. D'Alembert saw in Desmarest a kindred spirit, and helped him into the public service.

In fact, by 1763, the year we have mentioned, Desmarest had become a Government inspector of industries; and he turned aside, when in central France, to visit the high plateau of Auvergne. He preferred to make his geological excursions on foot. He missed none of the wayside quarries, and loved to converse with the workmen whom he found there. He always had his greeting ready for the peasants who passed him on the road, and, like many great Frenchmen, he probably never forgot that he was himself of peasant blood. "Moi, je suis homme du peuple," is a phrase you may hear any day, spoken without affectation, among the well-to-do citizens of French provincial towns. A group of labourers round the table of a country-inn thus gave Desmarest a pleasant reminder of the company and surroundings of his childhood.

Desmarest had by this time made a particular study of basalt, and he had learnt all that he could about the Irish Giant's Causeway. As he walked from one rock to another in Auvergne, he became more and more assured that the masses which seemed built up of columns were parts of true flows of lava. Basalt, he said to himself, is a volcanic rock; in Auvergne we can see all the stages between it and what every one would admit to be a lava-flow. The basalts of other countries, however much they have been worn through in places by

streams or by the sea, must also have been poured out in a molten state. A century before, people had just begun to appreciate the wonders of the Giant's Causeway; and now at last the riddle had been solved. It was the real triumph of Desmarest's career, something added for ever to what we know about the earth.

In 1764, Desmarest persuaded the French Government to draw up an accurate map of the volcanic country of Auvergne. He accompanied the surveyors, and added largely to his previous observations. Here, one would think, the question of the origin of basalt was satisfactorily settled.

3. Rival Ideas about the Giant's Causeway

A great volcano, or a series of volcanoes, pouring out lavas year after year, sends one sheet in this direction, another in that, but in the end fills up all the irregularities of the country with layer upon layer of hard rock. Some of these layers may be a few inches thick, others may measure 40 or 50 or 100 feet. The thicker masses cool very slowly. As an example of this, in October 1906, we could light paper in the crevices of lava that had been poured out on the high slope of Vesuvius six months before. Specimens knocked off with the hammer had to be carried cautiously between our finger-tips until they had cooled

down in the keen air. Some Vesuvian lavas have remained as hot as this even for two years. Great lava-flows ultimately cool at the surface, cracking irregularly, and perhaps giving rise, as they shrink, to a number of small twisted columns. The lower mass, giving up its heat still more slowly to the ground beneath it, cracks from its under surface upwards, and forms far more regular and massive columns. The two portions of the lava-flow, with their different types of structure, meet finally along a certain level, and the flow looks as if it were composed of two distinct rock-masses. The tough roof of the caves at Staffa is formed by the upper portion of the basaltic lava of which the islet is a remnant; the sea has undermined the fine columns of the lower portion, and has worked its way back into the mass, forming the caves.

The Giant's Causeway, then, is formed from the lower portion of a lava-flow. Irregular lumps of the upper part still lie scattered on it; and numerous lavas with the characteristic double structure of massive flows appear in section on the cliffs beyond. Below the red band, the lavas are thinner, and are, presumably for that reason, not columnar. They look so regular, and the whole of Bengore has such a bedded aspect, that we must carefully trace out any given layer before we can recognize that the structure of the

cliffs is due to a number of overlapping lava-flows (Fig. 38).

Faujas de St. Fond, a French landowner in the valley of the Rhone, soon extended Desmarest's observations farther east to the Vivarais, and

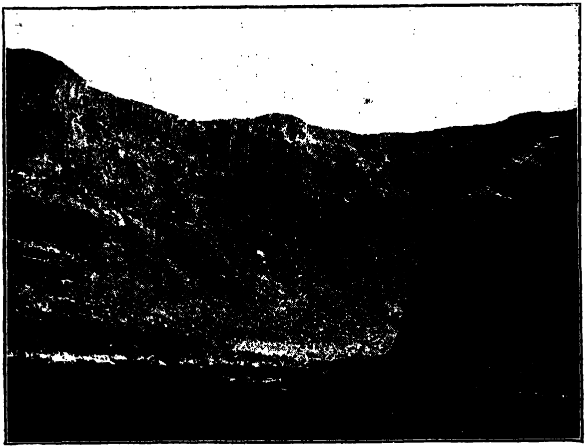

FIG. 38.—Cliffs formed by successive outpourings of basaltic lavas, near the Giant's Causeway, Co. Antrim. (R. Welch photo.)

showed that the fantastic rocks of Le Puy, one of the strangest towns in Europe, and the groups of columns so aptly styled "organs" on the flanks of the Cevennes, had been carved out of ancient lava-flows and volcanic ash. He used the term *pavé des géans* freely in his fine large volume published in 1778, and he clearly had no more doubt than

Desmarest as to the volcanic character of the basalts of the county of Antrim.

The Rev. William Hamilton was at this time rector of Condevadock, a small village in Donegal; but his scientific studies made him famous in Ireland as one of the founders of the Royal Irish Academy. In a letter dated 1784, and printed in 1790, he gives an excellent account of the Giant's Causeway, and quotes Desmarest in support of the view that the rocks of the neighbourhood were poured out from volcanoes. He even showed how the flints under these lavas had been altered by the hot masses that flowed over them.

John Whitehurst, an English geologist, also urged in 1786 that the Causeway rocks were true lavas, and suggested that the original volcano from which the basalt flowed had been swallowed up in the Atlantic Ocean by some convulsion. By this time, however, a strange alteration of opinion was setting in, owing to the teaching of a German mineralogist, Professor Werner, at the Mining Academy of Freiberg in Saxony.

Werner had handled minerals even in his childhood in the middle of the eighteenth century. His father was an iron-founder, who gladly encouraged the boy's taste by letting him turn over a collection of minerals at home, and by putting before him books on mining subjects. At the

age of twenty-five, young Werner had so impressed his teachers that he was invited to give lectures in the Freiberg Mining Academy, where he finally remained for forty years. He published very little; but his pupils were deeply impressed by his admirable powers of teaching. What concerns us here, however, is not the great work he did for mineralogy, but the views that he spread abroad regarding the origin of basalt.

Having found basalt in Saxony, with its characteristic sheet-like structure, and in a region where volcanoes are not now active, Werner announced in 1787 that this rock was deposited in a crystalline state from water. He was thus repeating a mistake made by Guettard, and he also agreed with this early French worker in erroneously connecting volcanic eruptions with the burning of coal-seams. In spite of all that Desmarest and Faujas de St. Fond had done in the intervening thirty years, Werner's authority as a teacher served to carry his ideas throughout Europe; and geologists soon became divided into two armies, bitterly opposed to one another. The *Vulcanists* justly continued to connect basalt with volcanoes, and the *Neptunists* held that all the rocks which we now know as "igneous," except undeniable modern lavas, were laid down in Neptune's element, the waters of the sea.

It is nowadays difficult to realize the strength and violence of a quarrel such as this. Neptunism, in some unhappy way, got connected with religious feelings, which at once put the other party greatly in the wrong in the eyes of unscientific people. The clergy, however, appeared honestly and honourably on both sides, as we shall see by returning to the story of the Giant's Causeway.

Even those who believed that basalt was once molten were divided into two parties. One of these, to which the great Professor Playfair belonged declared that basalt had never flowed out like lava at the surface of the earth. This was the view of John Strange, an English traveller, who had cleverly recognised "Giants' Causeways" in the north of Italy as far back as 1775. The truth of course is that some basalt has cooled in cracks and as sheets underground, while some has cooled after eruption on the surface. Our next point is concerned with an underground example.

The Rev. Dr. William Richardson knew the north coast of Ireland intimately. He found fossil shells in a dark rock at Portrush about 1798. Prof. Kirwan, of the University of Dublin, pronounced this rock to be basalt. Kirwan was an ardent follower of Werner, and attacked Hutton and others who differed from him with considerable vigour. Richardson, backed up by this authority,

described the layers of basalt along the Antrim coast as beds deposited from water. His colleague, the Rev. William Hamilton, had just been murdered by rebels in the county of Donegal, and was unable to rise up and correct him. At the same time, Richardson made a number of very shrewd and accurate observations. Neither he nor any Neptunist seems to have realized that the basalts in France had already been proved to be connected with volcanoes, or that no modern ocean is depositing any such rocks upon its floor. All these beds of crystalline rock, said the Neptunists, were laid down long ago, and the appearance of man on the earth marked a new era, in which the old order of events might never happen over again.

Playfair of Edinburgh felt strongly that basalt had once been molten. He examined specimens of the supposed basalt containing fossils from Portrush, and found that it was only a black shale that had been baked and made almost flinty by a mass of basalt which comes up into it (Fig. 39). Any one who now goes down from the hotels and lodging-houses of Portrush to the rocks at the little harbour can break off specimens for himself, and can see the once molten rock underlying the greatly altered calcareous shale. The flat layers of the shale are marked all over with the coiled shells of ammonites; but these evidences of life disappear when we

reach the surface of the crystalline igneous rock below.

Two keen English geologists, the Rev. Wm. Conybeare and the Rev. Prof. Buckland, came over to Ireland in 1813, and fully confirmed what

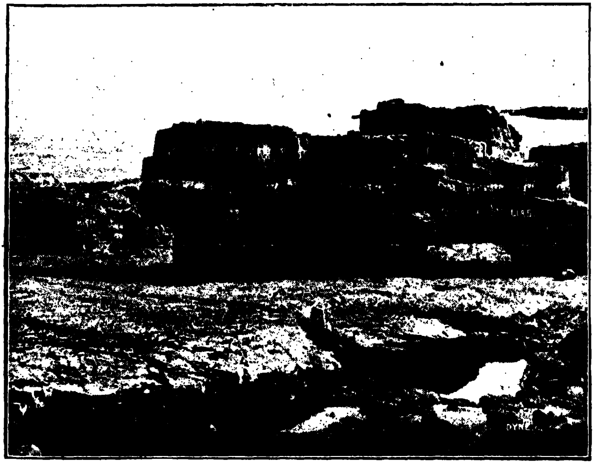

Fig. 39.—Fossiliferous strata baked by underlying basalt, which has invaded them from below. Portrush. (R. Welch photo.)

Playfair had described eleven years before. By this time, the Neptunists were becoming beaten; but, in spite of this, numerous papers on basalt by Dr. Richardson continued to appear. The heaviest blow dealt at the followers of Werner was the gradual conversion to Vulcanist opinions of one of his greatest pupils, Leopold von Buch. Von Buch

went to Werner's course at Freiberg out of a pure love for study. He was the son of a rich land-owner, and devoted himself in a long life to scientific travel. To see the ground intimately, to cross mountains, and to explore ravines, he would start out on foot, carrying with him all that he required. Full of Werner's opinions, he went to Desmarest's district of Auvergne, and afterwards to the volcanic lands of Italy. In the end, he threw aside much that he had been taught by the untravelled Professor at Freiberg, and came to recognize that basalt and granite were alike rocks that had once been molten in the earth.

This old controversy is worth remembering, since it shows what serious prejudices, and even personal dislike, men had to face while working out the problems of the earth. We are perhaps now wiser, and more kindly towards those who differ from us on scientific questions. Probably a greater attention to science in our schools and colleges may in time spread similar feelings towards those who do not agree with us on public matters. It would be a blessed day, for example, if persons on either side of the House of Commons, who are acting up to their convictions, could escape from being charged with all manner of uncharitableness by those who have come, just as honestly, to opposite conclusions.

4. The Volcanic Lands of Ireland and the Hebrides

But we are wandering from the fine old Giant's Causeway. Desmarest, Faujas de St. Fond, and Whitehurst clearly understood its volcanic nature. The Wernerians, who introduced all sorts of misunderstandings, have passed away like a bad dream. We can now look back with the still older observers to a time when the surface of the north of Ireland and the west of Scotland was dotted over with volcanic cones, pouring out lava, layer upon layer, from the mysterious cauldrons down below.

A few miles east of the Causeway, we see, at Carrick-a-rede, one of the necks through which the molten matter reached the surface. The last action here was vigorous and explosive, and blocks of lava lie heaped together, in a ground of finer material, just as they do round so many modern volcanic centres. The chalk, moreover, has been torn to pieces down below, and lumps of it have been thrown up, together with the lava. As a rule, however, in Antrim we have few traces of explosive action, and the lavas seem to have welled up quietly from a number of openings formed above long fissures in the ground. The lava that filled up these fissures, and finally hardened there, forms dark

"dykes" of rock, cutting across the stratified basalts and the underlying beds of chalk or sandstone. Even these dykes have sometimes cracked into columns, which lie perpendicularly to the surfaces

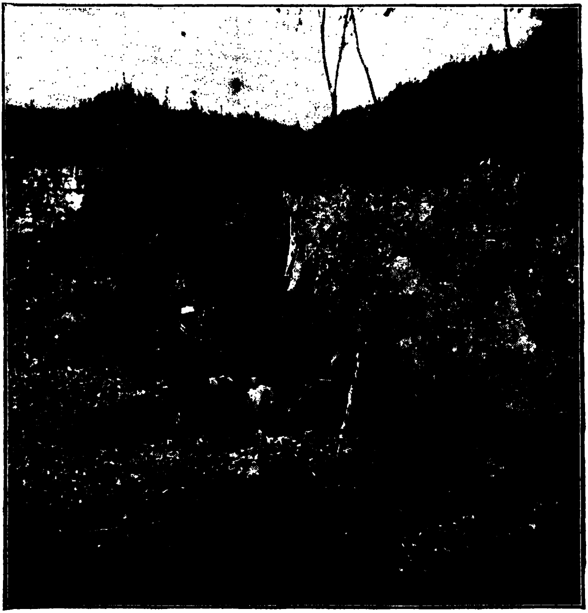

FIG. 40.—Volcanic Dyke of basalt cutting across grey limestone near Armagh. (G. Cole photo.)

of cooling, just as in the lava-flows, and are therefore in this case fairly horizontal. Similar traces of fissures up which lava flowed are found in the wild mountain-regions of Mayo and Donegal, and among the hummocky rocks of Down and

other counties, where no lavas now remain upon the surface. A dyke of the same age was formed in the north of England, the famous Cleveland dyke, which can be traced over a distance of ninety miles.

The great red band along the cliffs of Bengore, which Richardson and Hamilton both correctly explained as resulting from the alteration of solid basalt, represents a time of rest, when rock-decay went on and trees grew upon the surface of the lava. This peculiar red type of alteration, with the formation of bands of nodular iron-ore, is developed now in tropical climates where the rainfall is heavy at certain seasons. The plants found between the basaltic lavas of Antrim also show that our climate, when the volcanoes were active, was warmer than it is at the present day. Hence a careful study of the rocks shows us what the conditions of life were in the north Irish area soon after the chalk had been lifted high and dry from the sea-floor. The abundant dykes formed at this epoch show how the country must have been cracked and shaken, from the west of Galway to the north of Sutherland, and even to the east of Yorkshire. Sir Archibald Geikie has given us, in a series of memoirs, and in his work on the *Ancient Volcanoes of Great Britain*, an impressive picture of this great epoch of eruption. Professor Judd has studied in detail the volcanic centres in the

Inner Hebrides, and compares the mountainous masses that rose over Mull and Skye to Etna at the present day. The deep-seated rocks, once molten, have here come to light; but the widely spreading lava-flows also remain to us in great part, forming the desolate level uplands and the grim black terraces of these Atlantic isles. Perhaps we need not regret that such exciting times in our own area occurred so long ago, before any men existed on the earth. Yet we know well that under other countries at the present day the volcanic forces are very active, and have by no means spent their energy. Every now and then our old earth tells us that she has powers far, far greater than any that we wield ourselves, and that we cannot expect to spend our lives in undisturbed possession of her surface.

CHAPTER IX

THE MAKING OF MOUNTAINS

1. Three Kinds of Mountains

Seeing how rain and rivers, aided sometimes by glaciers, sometimes by wind-action, are always changing the surface of our earth, it is not surprising that mountainous masses are left isolated,

standing out above the plains. They are the relics of great stretches of rock which once covered a wider area. Often the beds of which they are composed are seen to lie horizontally, just as they were raised above the sea or the lake in which they were originally laid down. From one such mass to another across the country, we may trace the same series of deposits. The gaps between them have been carved out by denudation. Such mountains are "outliers," as we say, left behind in the general decay.

Great outlying masses of this kind can be seen along the west coast of Sutherland and Ross. Steep bare hills of brown sandstone, 2000 or 3000 feet in height, rise like huge fortresses above the hummocky lower ground. At sunset, the low light picks out their bedded structure, and they seem in the red glow like Egyptian pyramids that have been built up layer by layer. We know that Nature actually piled them up in this fashion, but in the form of broad continuous sheets of sand and pebbles, washed down from some still older highland and spread out over the uneven floor. The rivers that run seaward from the central watershed of Scotland have cut up the mass into the romantic mountains, Cul Mòr, Suliven, Quinag, and many others, which now seem to sentinel the shore. The vast amount of material that has been washed away

from between them was fully appreciated by John Macculloch, who described the western coast and isles of Scotland as far back as 1819. He drew a section to a true scale across the hills, filling in the broad gaps by lines of level strata. Sir Roderick Murchison wrote in 1854, "I have gazed in wonder at these mountains from a boat off the western shore, not only as proofs of the long period during which the boulders, pebbles, and sand were gathered together in former seas, but still more as evidences of the enormous subsequent furrowing out or excavation of the strata."

Where, again, "igneous" bosses exist, representing molten matter that oozed in among the other rocks and cooled there underground, denudation may cut away the material round about, thus lowering the general level of the country, while the hard crystalline rock remains standing up as a local mountain. The black Cuilin Hills and the pink granite masses close to them in the south of Skye have been formed in this way. So have the granite mountains, Cairngorm and the rest, on the eastern border of Inverness. These still rise 4000 feet above the sea, but with their crests rounded and smoothed by long decay.

Volcanic mountains have been described in Chapter VIII. The rock that cools in the throat of a volcano, as the activity finally dies away,

usually becomes crystalline, tough, and resisting. The rampart of tuff, ash, and lava round it is worn away in time; but the volcanic neck or plug remains, conspicuous as a mountain in the landscape. Slemish in the county of Antrim is a fine example, and numerous striking masses, bounded by sheer cliffs, rise in the volcanic lands of north Bohemia.

But the great mountains of the world, as we recognised when we found sea-shells far up among them, show signs of earth-movement and upheaval. The beds of rock in them are folded and contorted. Fractures accompanied by movement, known to miners as "faults," are traceable here and there on the huge rock-walls, and show that the strata have been actually dragged apart or thrust together, until they became broken through. As we draw near to the centre of the chain, we usually find crystalline rocks, which still, perhaps, retain a bedded structure, but which are evidently greatly altered. Nearer still to the core, there are often signs of greater crumpling and crushing, and also of considerable heating. We are now approaching, in ordinary types of mountain-chains, a central core of granite, a huge bar, as it were, of igneous rock, intruded from below, and sending off numerous veins into the surrounding rocks. Some of these neighbouring rocks have become so closely and delicately penetrated by the granite when it was liquid, that it is hard to

say how much is granite and how much altered material of older date.

The central core, crystalline and resisting, usually stands out conspicuously when the mountain-

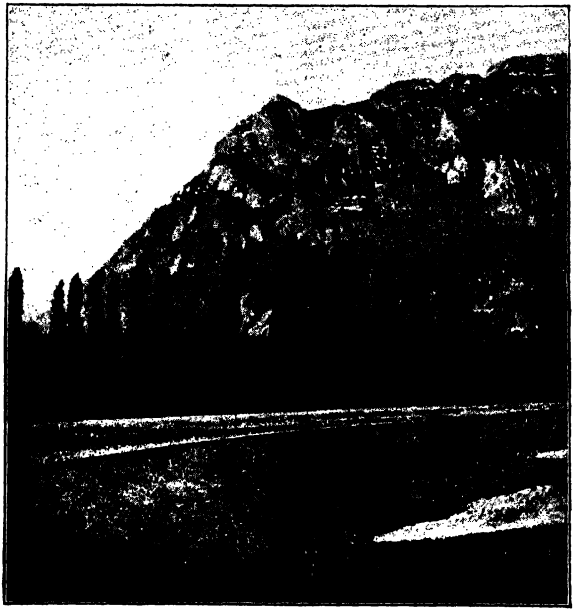

Fig. 41.—Folded limestones forming mountains near Montmélian, Savoie, France. A fault is seen high up in the centre. (G. Cole photo.)

chain is attacked by weathering. The grandest and wildest peaks, at times too steep for snow, are carved out of the crystalline igneous rock, which may form several separate masses in the range,

or perhaps a series of parallel chains, according to the room allowed for it as it oozed up from below. Now and then, the igneous rock, after it has cooled, has become folded into odd positions among the sedimentary beds upon its flanks; and in places it has been crushed, deformed, and streaked out by the pressure of these later earth-movements.

2. The Crumpling of the Crust

H. B. de Saussure, the Genevan professor, whom we have already met (p. 97) as the first scientific climber of Mont Blanc, recognized this general arrangement of the rocks when he made journey after journey in the Alps. The teaching of Professor Werner at Freiberg in Saxony then possessed great influence in Europe, and the granite core of the range was, according to him, the oldest rock of the globe, against which the others had been laid down in later times.

The true succession of the rocks may seem at first a small matter; but it opens up a tremendous picture of the past history of a country in which such mountain-chains occur. It was a long time before the facts were generally understood. As in all such cases, the man who loved nature in the open air, and who walked across the heather and the bare rock-faces, had the pleasure of finding out the

truth, and of handing it on to others, like a lighted torch. James Hutton of Edinburgh felt, when he was writing his paper on the *Theory of the Earth*, that granite must have entered into the hearts of mountains in a molten state; but he was then unable to go as far as Switzerland to prove it. Fortunately he and a friend, Mr. Clerk, had business with the Duke of Atholl in 1785 at his house on the edge of the Grampian granite in Glen Tilt, and the visitors were delighted to find the rocks washed bare in the river-bed, and showing them precisely what they desired. Hutton saw that the granite had broken into the strata on its margin, and "had been made to invade that country in a fluid state." In order to make sure, he went with Mr. Clerk in the next year to see the granite on the Galloway coast, where it rises as a noble dome known as Cairnsmore of Fleet, overlooking Wigtown Bay. To use his own words, the friends saw that "the granite had invaded the schistus or Alpine strata [*i.e.* the strata resembling those on the margins of the Alps], having not only broken and floated the schistus in every way possible, but . . . we found the granite introduced, for some length, in small veins between the stratified bodies, giving every mark of the most fluid injection." In 1787 Hutton visited Arran, with Mr. Clerk's son, and

waited three years more before he put his results into the form of a short but memorable paper.

This publication raised quite a controversy with Werner and others on the Continent, and with some workers nearer home in Edinburgh; and in 1807 and 1808 Prof. Playfair and Lord Webb Seymour walked over the Glen Tilt country, making very detailed notes. Some of the discussion might have been saved if both parties could have regarded igneous rocks as very hot solutions. Water certainly enters into their composition as they flow, and escapes in great part as they cool and harden. So far Werner might have been met; and we must remember that Hutton, in his *Theory of the Earth*, went much too far in his views as to the part played by melting in the making of ordinary rocks. However, the great point was now established; granite might be of various ages, having come in as a hot mass into strata of earlier date. Even Werner's own followers were now travelling over the world, and coming round to Hutton's views.

Leopold von Buch, the devoted pupil of Werner, visited Scandinavia some sixteen years after Hutton had described his observations in Glen Tilt. Von Buch was one of the best geological travellers who ever lived, and he had, thanks to his father's means and the education given to him, a fine knowledge

of foreign languages. He wandered through the forest-tracks of Sweden, and over the desolate and almost treeless wastes of Lapland. He examined the crystalline rocks which jutted up in the form of imposing mountains, or which were exposed in huge cliffs on the Norwegian coast. He was far too acute, in spite of what he had been taught by Werner, to mistake the part played by granite in this complex region. He saw that the granites belonged to different periods of the earth's history, for some of them overlay rocks which Werner recognized as younger than his primitive crust.

Norway, Sweden, and Finland to this day provide the most convenient fields in Europe for the study of granite veins (Fig. 42). Numerous workers have arisen in Christiania, Stockholm, and Helsingfors, to point out how the old north of Europe has again and again been invaded by molten rock, at times when the material of the present surface lay sunk into far warmer regions of the crust. A sort of kneading together of the ancient sediments has also gone on, and some masses have been thrust up over others, as they emerged again to form the backbone of Scandinavia.

Does the central granite of a typical mountain-chain push up the rocks above it, making space for itself by crumpling them back on either side; or does some strange movement take place in the

earth's crust, which produces a wrinkle into which the granite finds its way? G. Poulett Scrope, who taught us so much about volcanoes, believed in the

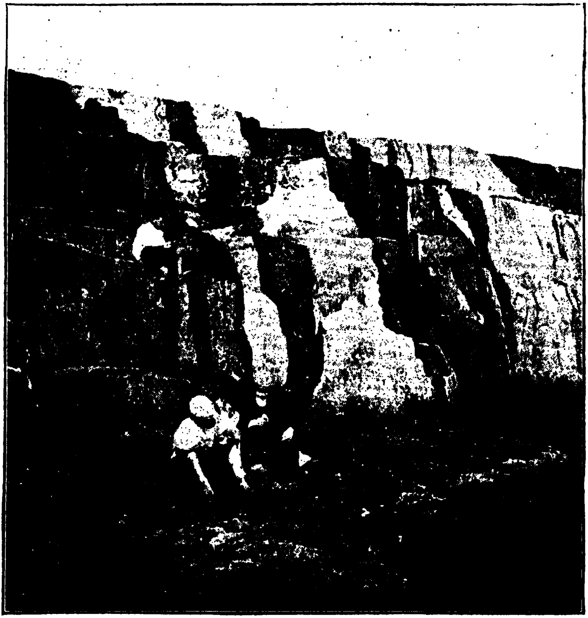

FIG. 42.—Granite veins in altered and originally stratified rocks, Helsingfors, Finland. (G. Cole photo.)

upthrusting power of the granite. The bedded rocks above it, he urged, were broken through and fell back on either side. They thus made a series of folds, as he showed in a neat diagram, resting over on one another, like a toy cracker pushed

sideways. There is still much to be said for the idea that such folds arrange themselves by sliding, even in our great rock-masses.

But careful observation and mapping have shown that mountain-chains often have a one-sided structure. The rocks are pushed over one another by a force acting in one direction. Fold after fold is formed, the higher ones falling over on those below. Planes of fracture take place, and masses ride up over those that once lay above them, moving in this way many miles from their original position. All these movements go on slowly. We find no evidence of those sudden catastrophes and explosions in the crust in which Scrope and other early geologists rather naturally believed. So slow are the earth-movements, that denudation, acting all the time on the uprising mountain-chain, carves out many features of the landscape before the region comes to rest. Pieces of the upper folds are thus cut off from the parts where the folds started, and remain as "outliers" in odd positions, calling for mountaineers to climb up among them and explain them.

It is very probable that the Himalayas, and even our familiar Apennines, are still growing, though men and animals, forests and cultivated lands, are found comfortably established in the valleys on their flanks. In India there is an ape, Semnopithecus, whose ancestors, similar enough to receive the

same scientific name, have left their bones in beds that are now crumpled among the foot-hills of the rising chain.

3. The Roots of the Mountains

The great mountain-ranges of the world are, in fact, great because they are still young. Some of them are increasing in height, so to speak, while we wait. But, when they come to rest, denudation will assert its levelling power. Already the external forces of our changeful world are tearing at the crests of the folds, and cutting deep grooves even across the crystalline cores. However much molten matter there may be in the region of unrest below, the igneous rocks, by the time they are brought up to us by folding processes, have become crystalline and cold. Here and there, lines of volcanoes break out along some crack in the lower ground, like those that mark the south-west shore of Italy. These volcanoes may show that the crust is weak and moving; but they lie at some distance from the central chain.

In time, then, the range must inevitably grow smaller. Its craggy summits, the scene of huge rock-slides and avalanches, must decay into mere rounded hills. The lowlands will be cumbered with material washed down by the streams, or broken off by frost, or rain, or alternate heat and cold.

The rounded hills themselves will pass at their edges into the plains. At length it will be hard to realize that a great mountain-chain existed in the country. Only the roots of it will remain, relics that rise perhaps 2000 or 3000 feet above the sea, with broad valleys worn out between them, and meadow-lands where once the snow-peaks towered.

The geologist, like a historian working over the tombs in a deserted graveyard, strives to bring together a picture of the past. He sees the connecting links between the outliers, and traces the forms of huge earth-folds through a number of disconnected hills. It was hard enough for the Swiss and German workers, Heim, Schardt, Rothpletz, if we name only a few, aided by others, such as Marcel Bertrand, from over the French border, to read the contorted structure on the huge rock-faces of the Alps. But, thanks to them, we may now recognize nearer home traces of the mountains of other days, though the working out of the story requires patience and devotion in a high degree.

The Scottish highlands have proved attractive to geologists, as they have to all lovers of fine scenery. The geologist enjoys scenery more fully, perhaps, than any one, since he compares one feature with another, and is always on the look-out for some new point that may explain the history of the landscape. John Macculloch and Sir Roderick

Murchison, both energetic and somewhat fiery Scotchmen, tramped in old days as geological pioneers over the moors and mountains. James Nicol, the Aberdeen professor, showed how the older rocks had there been pushed up over younger ones. But it was not until Professor Charles Lapworth came into the field about 1882 that we began generally to understand that in these highlands we

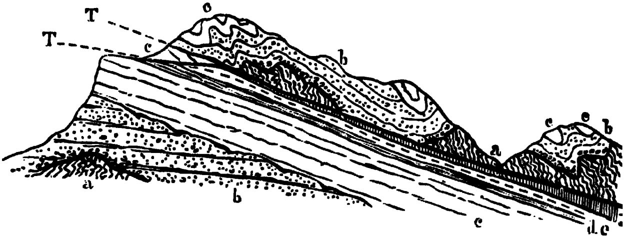

FIG. 43.—Older Rocks thrust over younger ones by oblique faulting in the Scottish Highlands. *aa*, Ancient gneiss; *bb*, Torridon sandstone; *c* to *f*, Cambrian strata; *TT*, oblique faults or thrust-planes. (From Sir A. Geikie's *Class-book of Geology*.)

were walking over the worn-down roots of an ancient mountain-range. Lapworth, followed by the officers of the Geological Survey, mapped out the squeezed and broken rocks in detail. Masses were shown to have been pushed twelve miles or so out of their proper place by earth-pressures (Fig. 43); and, later, similar movements of eighty or ninety miles were traced in central Sweden. In considering whether such movements of solid rock are really large or small, we must always remember that the

earth is a ball, the circumference of which measures some twenty-five thousand miles.

In 1910, Mr. E. B. Bailey urged that great pushed-over folds, like those of the Alps, occur in the mountain-roots revealed in Scotland, in addition to the faults and shiftings already known. It is clear that we once had in our own islands a majestic range, which was worn down to a mere remnant long before our beds of coal were formed.

4. Old and New Mountains

The geologist thus traces the worn-down mountain-ranges even in the level lands. The earth itself often aids in their disappearance, by lowering the folded region again beneath the sea. New strata are laid down over the ancient crumpled folds; first the sands and pebble-beds of the shore, then perhaps muds and clays, spread out in deeper water, and then, in a pure unbroken sea, the white limestones formed of tiny shells. These may also be pushed up in their turn, and then the older masses on which they rest will form a firm basis to new hills.

In all our continents we thus find mountains old and new. The direction of one series of earth-wrinkles crosses that of another. If we remember that the highest mountains rise about five miles above the sea, and that four thousand miles separate

them from the centre of the earth, these wrinkles do not appear so very large. Look at forty centimetres (four hundred millimetres) on a metre scale, and think of this as a radius of the earth. The height of a mountain-range would measure only half a millimetre. There is plenty of room for old buried mountains down below.

The oldest mountains in the British Isles are represented by the floor of gnarled igneous rock which seems to underlie all our area. It comes to the surface in the Outer Hebrides, where long weathering under glacial action and Atlantic storms has worn much of it to a peneplane, on which lie numerous little lakes. A ridge of it still stands up in England as the Malvern Hills, the finest feature of the Midlands. In later but still early geological times, the Britannic region was folded from the south-east to the north-west, and the highlands of Donegal and Mayo, the Leinster Chain with its granite core, the tumbled land of Wales, and the great mass of the Grampian Hills, rose on a new continental surface. These ranges were continuous with those of Scandinavia, and the direction of the north-west edge of Europe still records the power of these early movements in rearing barriers to resist decay (Fig. 44).

Long, long afterwards, after the forests had flourished that gave us our great beds of coal, a new

series of folds was set up from south to north. These are well seen in the crumpled structure of southern Ireland, and they run boldly through South Wales, culminating in the sandstone hills of Brecon.

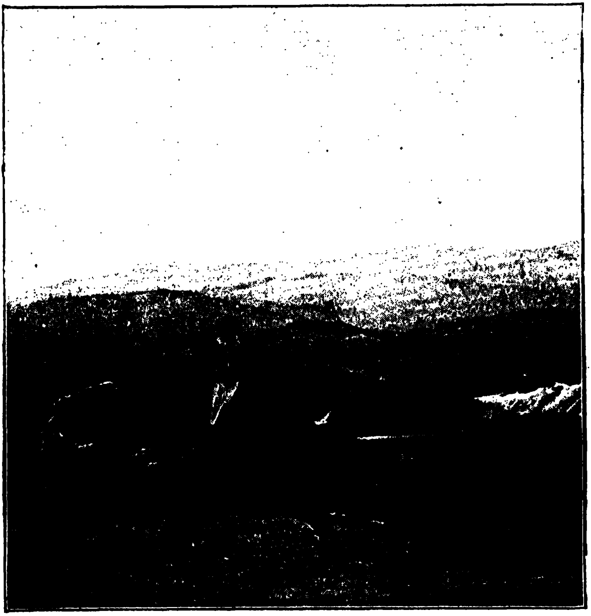

FIG. 44.—Old granite ridges, with altered shales and sandstones, representing the roots of former mountains, above Doocharry Bridge, in central Donegal. (G. Cole photo.)

Then they sink beneath later sediments; but they have been traced in deep borings, made for coal or water, all the way eastward under London, where the Gault clay, lying beneath the Chalk and

London Clay, rests in places on the buried mountain-ridge. These folds come to the surface in Belgium, and can thence be followed into central Germany. They control the form of Brittany, and many mountainous blocks to the south-east were pushed up at this same epoch, while the surrounding areas sank away from them as they rose.

Immense changes, however, occurred in the European area before the modern continent took its shape. The barriers of folded rock which have so greatly influenced the relations of human beings are of far younger age than that which lies hidden under London. In our isles, these latest and most important wrinklings are recorded mainly by the gentle folds of the Cotteswolds, the Chilterns, and the region of the Weald. A suggestion of severer crumpling is seen in the Dorsetshire and Yorkshire coasts. The bands of flint in the Chalk of the Isle of Purbeck and the Isle of Wight are boldly uptilted and bent in folds, as many of us know who have sailed under the fine white cliffs. The shell-beds of the Paris basin were at the same time lifted high and dry; but we do not find serious evidence of recent mountain-building till we reach the Juras and the Pyrenees. Here, and still more in the Alps, we recognize beds of the age of our Chalk and London Clay lifted up and squeezed so as to form craggy precipices 10,000 feet above the sea.

The Alps, a noble part of this new scheme of mountains, run eastwards to Vienna, and there branch out into farther ranges. The Carpathians, for instance, ring about the great sunken area of

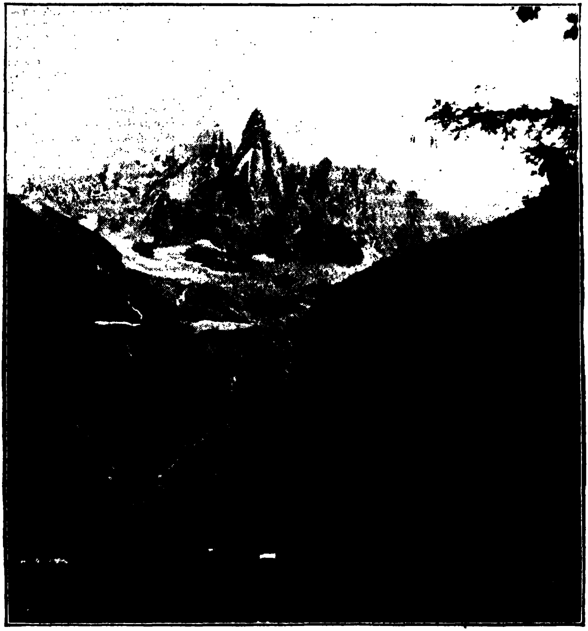

FIG. 45.—Young granite peaks of the Alps. Aiguille du Dru (12,513 ft.), Chamonix, France. (G. Cole photo.)

the Hungarian Plain, while the high plateaus of Dalmatia pass on into the folded region of the Balkans and the spurs of Greece. All this mountain-structure represents the skeleton of modern Europe,

and the decay of these mighty ranges is now gathering on the lowlands along the Rhine, the Danube, and the Rhone. The Apennines, which are still younger than the Alps, have stretched out boldly into the Mediterranean; and on their flanking foot-hills, which contain shells like those of the modern seas, the Roman nation was born that civilized the western world.

So, when we speak of young mountains, we are none the less dealing with times long before man came upon the earth. The mountains of the human epoch are no doubt being slowly formed beneath our feet. This active globe of ours has shifted the bounds of continents and oceans many times before land and water became the heritage of man. It shifts them still, and man often has to pay the penalty of planting his cities too near the regions of unrest.

Yet even the oldest mountains have influenced the life of man. The Lapps sought shelter among the desolate relics of the Scandinavian range before the advance of tribes from Baltic lands. The hardy Norsemen, again, were strengthened by life among these ancient hills. The virtues of hospitality and personal devotion, and a mistrust of the life of lowland cities, have been nurtured among our highland races in the equally old mountains of Scotland and Donegal. Brittany and Bohemia, with their dis-

tinctive communities, were isolated from their surroundings by earth-movements that took place soon after the coal-forests passed away. It is unnecessary to point out how the newer ranges have marked out political boundaries and influenced the modern map of Europe. Whoever studies geography will want to know something of geology; whoever studies geology will find that it begins and ends in geographical ideas.

5. Causes of Earth-Wrinkles

When we are asked why mountains are built up by earth-wrinkling along certain lines, it is best to answer at once that we do not know. Some mountains appear to be pushed up from below as huge blocks, bounded by faults, and their strata remain fairly horizontal. Their summits form upraised peneplanes or plateaus, until they become cut into by the frost and rain. Structures of this kind prevail in the central Rocky Mountains. But it is quite possible that these vertical movements are due to squeezings of the same kind as those that have crumpled up the strata of more ordinary ranges. Professor Penck of Berlin is inclined to attribute much of the movement in the Alps to direct upthrusting from below.

Professor E. Suess of Vienna has again and again directed attention to the formation of

mountains by the falling in of the earth's crust. That is to say, blocks become left stranded at the original level, while the areas round about sink downwards. We must thus always remember that a mountain may owe its height above its surroundings to movements that have taken place in two directions.

The great sliding movements, by which older rocks become thrust over newer ones, are almost certainly due to horizontal compressions of the crust. Perhaps it is wise, with Dr. Ampferer, to look for the causes of these movements far down beneath the cold rocks that we know. There seems nothing in the geological features of the surface to tell us why a mountain-chain has been built up along a particular line. There is great reason to believe, though we have never visited those regions, that there are huge reservoirs of molten rock under the solid crust, and the gradual cooling of these may set up stresses in the rocks above. There may be something like a highly heated and yielding layer extending right round the globe; that is to say, without troubling ourselves about the possible conditions in the core of the earth, there may be a liquid layer between it and us at all points. Disturbances in the balance of the solid crust may arise from disturbances in this liquid layer. If we watch a pot of molten lead cooling, a scum of solid lead is seen

to form upon the surface. If we tilt the pot slightly, the movement of the hotter and liquid metal below drags and wrinkles the cooled surface. In the earth's case, even the action of denudation may affect the liquid layer, weighing the crust down into it in one place and allowing it to bulge up under a crust-fold at another. The weathering of our uplands is merely a process by which the load at one part of the surface is transferred to another part. The part that is lightened may rise, while the plains or the sea-shores that receive the alluvium may be pressed down. One result of this will be that a mountain-mass is not worn down to sea-level so soon as it otherwise might have been.

But now we have said enough to show that even the mountains have not always stood where we find them at the present day. Like so many other features, they are merely signs that our earth is not a dead planet, but is still full of vigour and very much alive.

CHAPTER X

A YEAR OF EARTH-STORM

1. The Record of Twelve Serious Months

In the long history of the earth, there are epochs of comparative quiet on the surface, and others of

vigorous unrest and mountain-building. Similarly, within the short term of our own lives, we may notice certain calm years, and others marked by veritable earth-storms. Dr. John Milne, the untiring student of earthquakes, tells us in a recent review that "on an average a little earthquake occurs in the world every fifteen minutes. Great earthquakes occur on the average about every four days, but it is only on rare occasions that they hit populated districts." Hence we must be careful in discussing any year in which great disasters through earth-shocks have occurred to the human race. Such a year may not be altogether exceptional in the number of its earthquakes, but only in the grouping of them under cities. None the less, as an example of what the solid crust of our living globe can do, the twelve months from 31st January 1906 to 14th January 1907 are still fresh in the minds of many of us, and their record is well worthy of remembrance.

Populous places had suffered terribly by the catastrophes of the Central American region in 1902 (see Chapter VII.). On 4th April 1905, some 20,000 persons perished in India through an earthquake in the Kangra Valley, north-west of Simla, on the flanks of the Himalayas. A line of earth-fracture is known to exist along the outer edge of this great chain, and from time to time

movements and slips occur along it, which deal destruction in the cultivated lands on the slopes towards the plains. In 1905, however, no uplift or depression was traced on the surface after the earthquake. The sharp shock took place, and things settled down again much as they were before. The zone of folded rocks on the margin of the Himalayan mass contains very modern strata, and we may fairly conclude, as we said on p. 183, that the mountains are still growing, and that the Indian border is, geographically as well as politically, a region of unrest.

On 8th September 1905 one of the earthquakes for which southern Italy is unfortunately famous shook Calabria, and attention was again directed to the dangers that lurk for us within the earth. The shocks were felt throughout Sicily, and as far north as Rome; houses were wrecked, and hundreds of villagers lost their lives. Italy, again, may be regarded as still moving; it is, geologically speaking, almost the youngest child of Europe, and has grown out (p. 192) as a barrier across the Mediterranean even since the Alpine chain became established in the north. The volcanoes that are so well known on its western flank, beginning with the extinct ones near Rome and ending with a spot in the sea between Sicily and Tunis, are signs of the treacherous nature of the crust. On 28th December

1908, this fact was once more brought home to us by further terrible havoc in Calabria, and by the total destruction of the flourishing seaport of Messina.

The year A.D. 1906 included the following indications of an earth-storm. On 31st January a disturbance in the sea-bottom off the coast of Colombia, in the north of South America, sent out shocks that ruined many towns and villages, and hurled devastating waves upon the shore. Here we recognize the line of earth-movement studied by Darwin long ago. The huge chains of mountains from Tierra del Fuego to Alaska, bordering the Pacific Ocean, in themselves point to a long-continued crumpling of the crust. On 17th March, right away on the other side of the Pacific, an earthquake killed 1200 people in Formosa and wrought such havoc among the primitive native houses that there was comparatively little left for a second attack in April to destroy. It is said that a fort erected by the Dutch on the coast of the island in the seventeenth century was long ago lifted inland by a movement of the ground. Here again the region of unrest is marked by the presence of volcanoes.

On 4th April our familiar volcano of Vesuvius was in serious eruption. Lava soon flowed from a fissure that opened near the base of the great cone,

and it entered the village of Bosco Trecase, four kilometres distant, on 7th April. Roads were crossed by the molten rock, the railway was destroyed, and the lava only stopped at the cemetery of Torre Annunziata, near the coast. Enormous clouds of dust were meanwhile exploded from the summit of the mountain, rising some 40,000 feet into

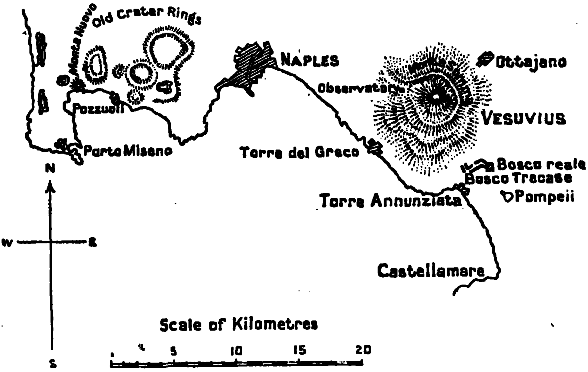

FIG. 46.—Map of the country near Naples.

the air. In the villages of Ottajano and San Giuseppe, the weight of ash and scoriæ, falling across the country, caused roofs to break in, killing those beneath them. The activity lasted ten days, and surpassed any Vesuvian eruption since that of 1641. On 9th April the ash lay five centimetres deep in the streets of Naples; and some of it fell in Montenegro, two hundred and fifty miles away across the Adriatic Sea. One hundred and fifty thousand

refugees poured into Naples from the devastated lands to the north-east and east. Torre Annunziata itself became deserted. On 10th April the ash broke in the roof of the Monte Oliveto market in Naples, killing 14 and injuring 125 persons.

The whole surface of the country, vineyards, the roofs of villages, clumps of trees, and open fields, were now covered with a pall of grey-white dust. All the bright and varied colours had gone out of the landscape, and travellers arriving in liners from the Mediterranean felt themselves face to face with a catastrophe the extent of which they could only dimly realize. Nothing could be seen clearly even a hundred yards ahead. Dr. Matteucci, Director of the observatory high up on the side of Mount Vesuvius, stuck bravely to his post, but admitted that his situation was "very unpleasant and alarming." He sent reassuring messages down to Naples; but the hill-terrace on which the observatory stands was already burdened with great heaps of ash and scoriæ.

On 12th April it seemed that Naples was once more to be spared. The activity of the volcano began to lessen, though a heavy shower of ash, turning day to night, still fell on Boscoreale and Torre del Greco three days later. Many months elapsed before the roads could be adequately cleared, and solid lava remained in streets, courtyards, and

hollows of the local railways, as memorials of this great eruption of 1906.

When the air became clear once more, striking changes were seen to have taken place in the form of the Vesuvian cone. Since 1872, the crater had become filled up by a new "little mountain," like that observed by Sir W. Hamilton (p. 129), and Vesuvius had become truly conical. The outburst of 1906 blew away some 500 feet from the summit of the cone, leaving the mountain so much lowered that its crest was no longer visible over the encircling wall of Monte Somma as one approached it from the north-west. A new crater, 1200 feet in depth and more than 2000 feet across, was excavated in the cone, and from its treacherous edges blocks rolled continually into the gulf. At the same time, deep grooves were cut in the mountain-sides by the sliding of the loose scoriæ that had been flung out so copiously over them. Many years must now elapse before visitors can see what is going on in the throat of the volcano. At present, one looks down into a steam-filled hollow, in the floor of which there are frequent rumblings, signs of the activity that lies more than 1000 feet below one's feet. Stones from the crumbling walls are still being mingled with the new material ejected in the crater-floor. The grim history of Mount Vesuvius is by no means closed. (Compare p. 123.)

The Italian region thus set its mark on the register of the year of earth-storm. On 14th April, just as Vesuvius was quieting down, a second earthquake occurred in Formosa, more violent than that of March, but fortunately injuring only a few

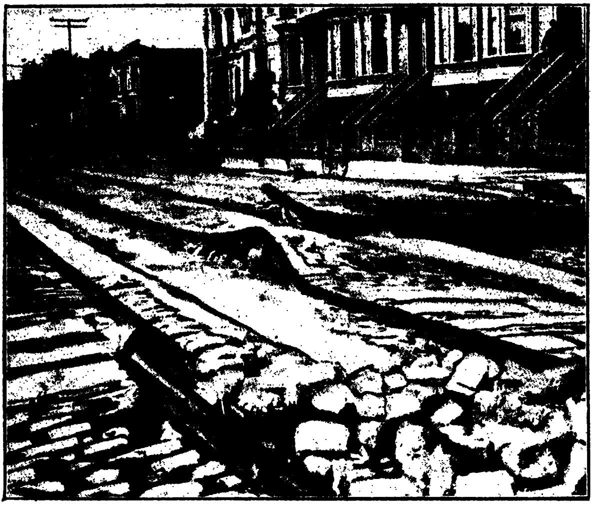

FIG. 47.—Tramway lines buckled by movement of the surface, San Francisco, earthquake of April 1906. (From *Bulletin* 324, *U.S. Geol. Survey.*) (G. K. Gilbert photo.)

people. On 18th April the world was startled as it had not been since the catastrophes of St. Vincent and Martinique. On the eastern margin of the Pacific, the floor of San Francisco was suddenly warped and twisted and broken by an earthquake that lasted for one minute and five seconds. The

huge commercial buildings rocked and cracked. Thirty-one slighter shocks followed one another through the day. Fires broke out freely among the wreckage, and by evening the city was involved in a great whirl of flame. San Francisco blazed fiercely for five days. One thousand people were killed, and 200,000 were rendered homeless.

On 16th August, four months later, there came a response from the Southern Pacific border. Valparaiso on the coast of Chile, and Santiago under the slopes of the volcanic Andes, suffered heavily from earthquake and from subsequent conflagrations. Early next morning, the accompanying disturbance of the ocean-floor was made known by a series of waves rolled in against the Sandwich Islands, nearly seven thousand miles away.

The autumn of 1906 brought no fresh disasters; but Kingston in Jamaica was severely shattered on 14th January 1907. As so often happens in connexion with earthquakes, the sea fell as much as 20 feet at some points of the Jamaican coast, and returned in a wave that swept the shore. The year of earth-storm may here be regarded as complete.

2. The Earthquake-Measurers

Shall we ever be able to predict the coming of an earthquake, or to indicate the most dangerous

portions of the crust? The great earthquakes in the sparsely inhabited districts of Central Asia, the numerous small earthquakes along the southern side of the Grampian chain, and the terrific catastrophe that destroyed Lisbon in 1755, all show the difficulties of the subject. Volcanoes are only distantly connected with great earthquakes. Where they occur, they may point out lines of weakness; but in many cases, without warning, our strongest towers may reel and our fenced cities may crumble into fragments before shocks that originate in the depths of the earth, and, therefore, far beyond our ken.

None the less, man the enquirer, man the indefatigable, has sought to measure and to comprehend the shocks of earthquakes. The intensity of a shock may be roughly measured by the amount of damage done to buildings. If these buildings are similar in various districts, some idea may be formed of the points where the shock emerged from the earth with most vigorous effect. But the most serious damage will be brought about, not immediately over what we may call the place of origin of the earthquake in the crust, but at some distance, where the shock was transmitted to the surface along a line oblique to the horizontal. Here buildings will become cracked by swaying, and not merely by vertical jumping up and down; and

portions of them are liable to be detached and thrown asunder. The same is of course true of cracked masses of rock, which may come tumbling down as landslides from the mountain-slopes.

Then, again, different kinds of rock respond very variously when they are called upon to transmit an earthquake-shock. The shock is passed on from point to point by a movement forward and backward again of the particles composing the rock. These particles, or rock-grains, are only loosely arranged in soils and gravels, but are closely in contact in granite or in the cemented sandstone known as quartzite. Scientific observers have exploded materials in various rocks, or have dropped heavy weights upon their surfaces. It is found that the shock thus produced travels about 1000 feet in a second through sands and soils, and at least five times as fast in compacter masses. A shock of great intensity at its place of origin travels faster than one of less intensity, and the results obtained by the patient measurers of actual large earthquakes often give results as high as 10,000 feet a second. The loose earths suffer most from earthquakes, and the houses stand best that are founded on the rock.

Robert Mallet, an Irish engineer, who became distinguished as a geologist and physical observer, was probably the first to study earthquakes systematically. Like the outbursts of volcanoes,

these occurrences tend greatly to disturb the minds of eye-witnesses. It is extremely difficult to note what is going on when the ground is heaving beneath one's feet, and when buildings or rocks are crashing down on every side. Mallet's first opportunity of putting his views and studies to the test came after the great earthquake that shook the country east and south-east of Naples in 1857. Numerous towns had been suddenly ruined, 12,000 persons had been killed, and wrecked buildings stood out over an area of six thousand six hundred square miles. Early in 1858, Mallet proceeded to Naples to study the remains.

Many of the towns on the flanks of the Apennines are perched on the tops of isolated hills. They have grown up round feudal castles, and to this day have extended little beyond their old encircling walls. With their tall towers, and churches with high false façades, they fell an easy prey to the tremors of the earth. In many cases, as on the steep coast-slope of Messina in 1908, one house slipped down on another, and a town collapsed with a sliding movement, like that of a structure built of cards. From the positions in which overthrown pillars lay, and from the directions of the cracks in houses, Mallet traced, not only the spot under which the shock originated, but the approximate depth of its place of origin. He gives, in his book on the

Neapolitan earthquake, a striking picture of the confusion amid which the earthquake-observer finds himself at first. He points out that one must climb to some height and look out over the scene. Things will then seem to have certain general laws of arrangement, and after this one can plod patiently from house to house.

Mallet determined the depth at which this great earthquake originated as about six miles below the level of the sea. He selected buildings in which a regular series of oblique cracks had developed, and imagined lines drawn perpendicular to the planes of cracking. Such lines from several buildings would meet in the heart of the earth at the place of origin of the shock (Fig. 48).

Dr. Charles Davison of Birmingham, who has done so much for the study and measurement of earthquakes, points out, in an interesting review of Mallet's work, that, when a shock is transmitted through various types of rock, its path is bent as it passes from a rock possessing one degree of compactness into a rock possessing a different degree. There is a bending or refraction of the line of transmission, just as light undergoes refraction when passing through transmitters of different densities. Hence Mallet's method can be only approximate; but it gave us our first idea of the nearness of the places where earthquakes originate to the actual

surface on which we notice their effects. In spite of all the more accurate measurements that have been made in recent times, we know of no earthquake-shock that started as much as twenty miles below the surface. The great Charleston earthquake of 31st August 1886 is believed to have originated

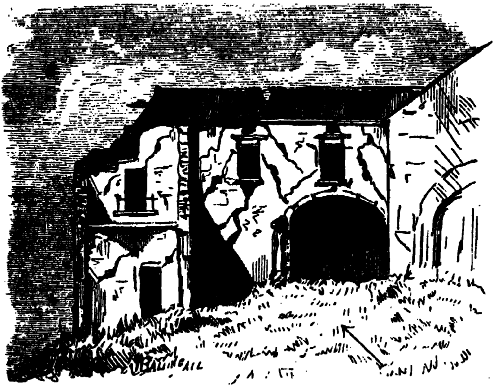

FIG. 48.—Building cracked by an Earthquake; drawn by R. Mallet. His conclusion as to the direction in which the shock emerged at the surface is shown by the arrow in the foreground.

twelve miles down, and from this comparatively small depth it affected, as Dr. Davison tells us, an area of 2,800,000 square miles.

Mallet had rightly concluded that the earth-particles swing forward under the influence of the shock, like the particles of air or of a solid that conduct a sound-wave to our ears. Recent work

has shown that the movement is highly complex, and involves many a twist and turn before the particles come again to rest; but it is clear that the walls of buildings, and even rock-masses, which are naturally not very elastic, may break open when thus set moving. Cracks appear, which remain gaping when all is again quiet; one part of the mass in such cases has been thrown forward away from the remainder. Mallet used these cracks in measuring the amount of swing given to an earth-particle by the earthquake.

Major Dutton, in his book on *Earthquakes*, gives us a clear idea of the destructive nature of small movements. Where rocks are said to have been heaped on one another, and great chasms to have opened up, it is probable that the small tremor which we call an earthquake has started a rock-fall or a landslide. Mallet's measurements near Naples showed parts of houses that had been thrown forward $4\frac{3}{4}$ inches (120 millimetres) from their original position. Dutton points out that the greatest amounts of movement from the original position occur on soft ground, and may be as much as a foot or more. On firm rock the movement is probably never more than 2 inches (51 millimetres). The earthquake is of course more dangerous if the movement takes place quickly. A movement of 10 millimetres in a quarter of a second will

crack walls, while twice that amount ($\frac{3}{4}$ of an inch) in the same time will cause wholesale destruction.

The direction along which a shock arrives at a spot on the surface is naturally in most cases oblique to the surface, and the movement of the earth-particles may be regarded as partly backward and forward horizontally, and partly vertically up and down. If the earth-wave that was started by the shock had run along the surface, the movement of the particles would have been, broadly speaking, horizontal. If it had come up vertically to the surface, their movement would have been vertically up and down. The movement in the case of an oblique direction may be supposed, then, to be split into two such movements. The modern instruments devised to measure earthquakes consist of two parts, one of which records the vertical and one the horizontal movement. These records are usually made on a magnified scale by a long pen attached to a pendulum-blob, which only moves in relation to the earth when the earth is set vibrating under it. From the two records, the true position of an earth-particle during an earth-tremor, or during a long series of tremors, may be calculated.

Professor Sekiya of Tokyo constructed a wire model to show the path followed by a particle during an earthquake in Japan in 1887. It was so complicated that it had to be made in three separate

models, copies of which may be seen in many geological collections. The position of the particle in successive seconds of the time during which the tremor lasted was indicated by numbers attached to the twisted wire. The shock lasted seventy-two seconds, and the details of the movement, as shown by the delicate instruments, could only be brought out by making the model fifty times the true scale. Here and there we notice in it considerable horizontal swings, and there are a number of almost vertical little leaps before we trace the particle to its final position of rest.

For a long time, however, no accurate means existed for observing the nature of an earthquake-shock. Early in the nineteenth century, Cacciatore's simple instrument was in use in Sicily. It consisted of a circular wooden dish 10 inches in diameter, with eight notches cut in its rim, facing the principal points of the compass. The dish was filled with mercury up to the bottoms of these notches, and a receiving-cup was placed outside each notch. When a shock took place, mercury was thrown out through one or more notches, and the direction in which the shock travelled in the earth's surface could thus be estimated. The quantity of mercury thrown out gave a measure of the intensity of the shock.

About 1850, Professor Palmieri of Naples estab-

lished a much more refined "seismometer" or earthquake-measurer in the observatory on the flanks of Mount Vesuvius. A weight was hung by a spring just above a basin of mercury, and the mercury and the spring were connected with an electric battery. The vertical movement of an earthquake-shock made the weight dip into the mercury, and an electric current passed. In the circuit of this current was the pendulum of a clock, which was started by the current, and the clock then unrolled a band of paper under a pencil. This pencil was also pressed against the paper by the current, and was released when the current ceased, so that successive shocks were thus recorded. Similar methods, involving the sway of mercury in tubes, were used to record the horizontal movements in two directions at right angles to one another, and from these the direction of the shock was calculated. The electric current started by the shock was also used to stop another clock and to ring a bell to call the operator. The moment when the earthquake began was thus recorded.

All this was a great improvement on Cacciatore's methods, though his instrument was also retained as a check in the Vesuvian observatory. As time went on, Professors Ewing and Milne and Gray invented seismometers depending on delicately suspended pendulums, which enabled very accurate

records to be taken, and they found a great field of work in Japan, where large and small earthquakes are unfortunately common. The observation of the Japanese earthquake of 28th October 1891, mainly by Japanese men of science, resulted in one of the most complete accounts, combined with accurate measurement, that we possess of any such catastrophe. It is from Japan, moreover, that we have learnt most of what we know regarding the kinds of earth-waves that are started by earthquakes, and also regarding earth-waves arriving from long distances.

The more that scientific men learnt about the movements of earth-particles in ordinary earthquakes, the less they were inclined to believe in the old stories of a visible heaving of the ground. Yet such large movements have now been frequently observed by persons not likely to exaggerate. Major Dutton points out that visible waves are associated with great earthquakes, and with the region directly over the place of origin of the shock. He describes their appearance vividly. "The ground is seen to be traversed with swiftly moving waves. Their outward forms as described by eye-witnesses exactly resemble flat waves on the water. . . . They are seen to tilt buildings, to raise and lower the pavements of streets, to swing and lash trees and telegraph poles, to hurl down in ruins brick or stone walls, to sway or even snap off

tall chimneys. The ground has been seen to open in cracks in the crests of the waves and close together in the troughs, squeezing out water thick with sand and mud, which is spurted upwards or which forms little craters around the vent-holes. The ground if soft and unconsolidated is often permanently distorted by these waves. Railroad tracks and road-beds partake of this distortion, which is often extreme."

The earth-storm may thus leave permanent traces of its passage. The instances in which large areas of land have been left upheaved or lowered after earthquakes, in one case by as much as 47 feet, are now known to be numerous. Some of these occurrences have been referred to in Chapter II.; but the careful earthquake-measurers are continually adding to our knowledge, not only of the earth-tremors, but of the more lasting movements of the ground.

3. The Causes of Earthquakes

Earthquakes commonly, as we have said, produce slipping of the loose rocks of the surface. The banks of rivers especially fall in, a number of cracks being formed parallel to the front of the bank, and the alluvium sliding outwards in broad blocks, which remain as a series of steps leading to the water. When, however, we come to consider the

cracks formed in the more solid rocks, along one side of which the surface is raised, or those along which a horizontal sliding movement has taken place, it is very hard to say if the crack is the cause or the result of the earthquake. If we could trace all earth-storms to explosions of steam in the throats of volcanoes, or in the heart of the earth itself, we might easily assert that the cracks result from the tearing asunder of the rocks under the shock. But our great earthquakes, as we have already pointed out, seem scarcely at all related to volcanic action. Moreover, cracks along which movement has taken place, the "faults" of miners and geologists, are traceable in every district where we burrow into the crust in search of minerals, or where we map out the rocks in detail and note how they lie in regard to one another. Some of the movements along these earth-fractures have gone on through immense geological ages. In the course of time, rocks have been moved thousands of feet away from those corresponding with them on the opposite wall of the fault. The rocks may be broken and ground together between the two walls, and the walls may be grooved and even polished by the friction of the fragments and of the rock-powder against them during earth-movement. But there is no evidence of a violent tearing asunder of the mass. The movement seems to have been steady

and gradual, no doubt with occasional pauses, and also with occasional sudden slips.

If we admit the occasional slips, may we not see in them the cause of many earthquakes? The crust of the earth is always in a state of strain. Denudation, the wasting of the surface, is continually transferring material from one portion to another. It cannot add to the load on one part without lightening that on another, and thereby upsetting the delicate balance of the crust. Lava, thrust out year after year from the basins of molten rock, similarly permits of a falling in of the ground above the cauldron. A trifling bending in at one point may mean a trifling thrust imparted to another. At this second point, however, things have been going badly for a long time. Dragging stresses have been in existence, and faults have long ago begun to grow. The critical push comes, and a sudden slip takes place along the plane of weakness. The abrupt movement may even result in a snapping asunder of rocks that had remained hitherto unbroken. An earth-wave is sent out on either side, and this may affect the surface as an earthquake. It may, however, have been started by an untraced disturbance of balance hundreds of miles away. From a small beginning, the earth-storm bursts upon us, and the whole earth feels and trembles.

Mr. R. D. Oldham, who has made memorable

studies of earthquakes in India, believes that we must look for the causes of great earthquakes in

FIG. 49.—Map of the San Francisco peninsula, showing principal fault-lines. (From a model by Professor Lawson; *National Geographic Magazine*, 1906.)

the sudden displacement of matter far down in the

crust, or even below it. The faults in the surface-layer show us, according to this view, that something on a larger scale has occurred under our feet.

A connexion has been made clear between the earthquakes that have occurred at San Francisco and lines of fault that cross the country from

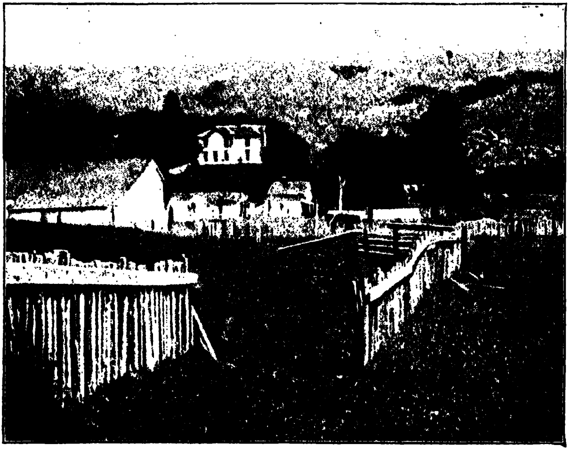

FIG. 50.—Fence parted by horizontal movement along the fault, San Francisco, earthquake of April 1906. (From *Bulletin* 324, *U.S. Geol. Survey.*) (G. K. Gilbert photo.)

north-west to south-east. Two hundred earthquakes were recorded in this region between 1850 and 1886. After the great shocks of 1906, visible evidences of slipping appeared over a distance of one hundred and eighty miles. The movement in this case was mainly horizontal. Roads were cut across

and shifted sideways, and fences were similarly broken in the fields. Ordinarily, a huge furrow appeared in the surface, along which, as Professor G. K. Gilbert writes, "the ground is splintered, and the fragments are dislocated and twisted."

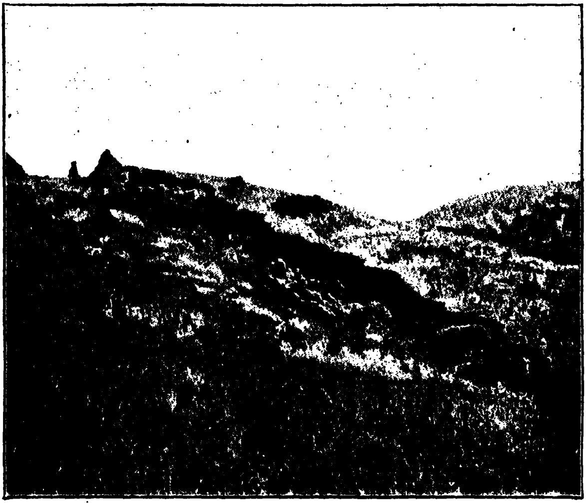

FIG. 51.—Cracking of the ground along the line of fault near Point Reyes Station, San Francisco, earthquake of April 1906. (From *Bulletin* 324, *U.S. Geol. Survey.*) (G. K. Gilbert photo.)

The horizontal movement sometimes amounted to 16 feet (Figs. 50 and 51).

One of the great faults that cross the peninsula of San Francisco has already shifted the strata vertically by 7000 feet. Marine beds of recent geological age have been folded in this district, and

elevated 2000 feet above the sea. The catastrophe of 1906 is clearly only a step in the majestic earth-movement which has reared, as Darwin so long ago recognized, the eastern wall of the Pacific. Earth-storms are mere incidents in that rearrangement of continents and ocean-basins which is always going on upon the surface of the changeful earth.

CONCLUSION

In this little book, we have only just entered on a wide study, which must, after all, be carried on by observations in the open air. The earth itself will tell us of the animals and plants that lived on it in times long past, and their remains must be sought in quarries, or on the unbroken mountain-side. There we shall see, thanks to those who have gone before us, how the sea-floor and the land have changed places, how ice once flowed across our fertile country, and how rain and rivers are carving out new features in the hills. Geology is far more than a collecting and naming of things found. It brings us face to face with the old Earth-mother, in gloomy caverns or in sunny cornlands of the plains; and we hear her voice still calling to us, as it called to the first children who stood wondering on the fringes of the woods.

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THE END

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